THE GEOLOGY OF THE BLACK BIRCH FAN AND CATCHMENT, MT. COOK NATIONAL PARK, AND ITS RELATION TO PROPOSED ENGINEERING STRUCTURES.

A thesis submitted in partial
fulfilment of the requirements
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by

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ABSTRACT.

Pressure on tourist facilities at Mt. Cook has forced development on to the recently active Black Birch fan surface. The 479ha catchment behind the fan contributes sediment to the fan along a steep stream channel. Climatic conditions are severe; vegetation and soils reflect this. The area is within the Torlesse Group of rocks and consists of interbedded greywacke and argillite with a fault-bounded schist block. Structural features trend north-south. Pleistocene glaciations between 5,120 and 530 years B. P. deposited 150m of outwash material in the catchment which has since been dissected. Extensive areas of scree are present.

Tractive-force studies on the fan indicate a decrease in energy down-fan. The progressive increase in stream sediment size downstream indicates an oversupply of sediment to the upper reaches of the stream. Hypsometric analysis shows that 50% of the area is below 40% of the total relief. Average catchment slopes have been calculated at 38°. Avalanches descend the stream channel in winter.

The concept of geological risk is discussed and geological risks to the fan are identified. Earthquake risk is classified in a regional context, but little contemporary evidence supports the high risk classification. Flood risk is discussed in detail; approximations of stream discharge and channel capa-

city are calculated using empirical formulae and the stability of the materials in the channel to these flows is calculated. Damage to the channel from a discharge with a return period of four years is suggested but because of the number of assumptions in the calculations a significantly greater discharge will probably be required to flood the fan. In social and economic terms the geological risks are probably acceptable. Continued necessary channel maintenance will be detrimental to the environment.

1. GENERAL INTRODUCTION

1.1 INTRODUCTION

In New Zealand, as in other countries, it is inevitable that buildings in an alpine environment are at a higher risk than buildings in most lowland areas. The risk is from the natural environment, and the reason is the great tempo and severity of the processes within the environment. The Black Birch fan, within the Mt. Cook National Park, is in an area where the alpine environment is perhaps at its harshest. The purpose of this study is to assess the geological risks to buildings and other structures on the Black Birch fan, and not to condemn or support the use of the fan as a site for buildings and other structures.

The assessment of risk to the buildings and structures necessarily requires two steps: the environment has to be studied and described, and the risk then has to be assessed taking into account knowledge of the environment.

Essentially the study of the geological environment and the effect it has on the buildings and other engineering structures falls in the realm of engineering geology. However the term engineering geology is often strictly applied to the very close relationship between a structure and the geology; the more distant relationships, such as those in this study, are often covered by the term "environmental geology". There is an implication that the environment is of more importance than the structures. The environment has therefore been studied in detail and this has resulted in the addition of some new information on small mountain catchments, on the formation and present structure of alluvial fans, and on glacial deposits within the Mt. Cook National Park.

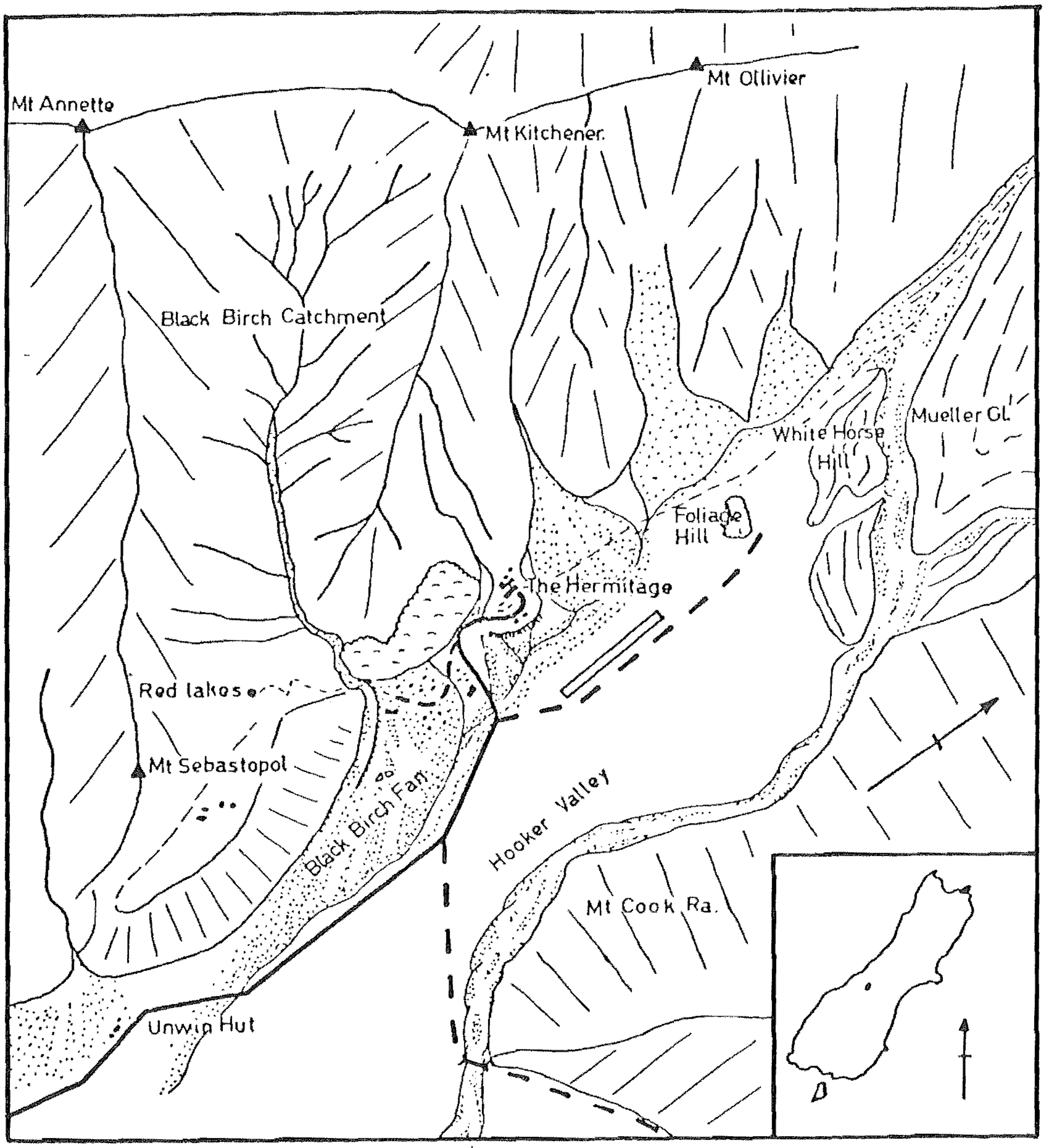
Apart from solving the primary objective of assessing risk, the study has the intention of demonstrating the practicality and usefulness of a number of methods of study, for example the quantitative study of fan deposits and slopes, and empirical methods of flood estimation.

During the course of the study, several features that could warrant further work, especially with emphasis on New Zealand conditions, became apparent: for example, the vertical variation in climate, the action of avalanches as geomorphic processes, methods of quantitatively describing glacial and stream deposits, and finally, the detailed nature of the greywacke and schist structures.

1.2 LOCATION AND MORPHOLOGY.

The Black Birch study area consists of a small catchment (479ha) and fan located to the south of the present Mt. Cook village in the Mt. Cook National Park. (figs 1 & 2). Black Birch stream trends east-west from the apex of the fan at 755m elevation to the Sealy

Fig.1 Location of the Black Birch study area.



derived from air photographs.

Fig. 2 Black Birch catchment and fan from the slopes of the Mt. Cook range. In the foreground the Hooker Valley with the Black Birch fan and the Hermitage. Mt. Sebastopol is the dark peak on the left, Mt. Annette is in the centre distance, and Mt. Kitchener is to the right. The Great Groove fault can be seen above and slightly to the left of the fan apex.

Range, where Mt. Annette (2230m), Mt. Kitchener (2002m) and the Waihi Pass (1941m) form the western boundary of the catchment. A ridge between Mt. Sebastopol (1462 m) and Mt. Annette forms the southern boundary of the catchment, and a ridge from Mt. Kitchener to the Hermitage forms the northern boundary.

The catchment slopes are steep, with large areas of bare rock and scree at high altitudes, while at lower altitudes moraine deposits and debris from the slopes are less steep, deeply-gullied, and covered with vegetation. Ephemeral streams at high altitudes coalesce to form a permanently flowing stream in the valley floor.

There is a steep-sided gorge above the apex of the fan where the stream leaves the valley. In the past, the stream used to flow out over the fan, but works carried out since 1966 have channelled the stream along the southern boundary of the fan.

A conoid fan-surface has its apex at the lower end of the gorge. To the west the fan surface abuts the Glencoe fan, and to the south it extends along the base of Mt. Sebastopol. The surface of the fan consists of old stream channels, some of which are covered by tussock and low plants, but the major area is virtually bare. The overall slope of the fan surface is about 3°.

1.3 HISTORY OF LAND USE AND DEVELOPMENT.

From the earliest European times, the potential of the Mt. Cook region as a tourist attraction has been high.

The current nature of development is the result of the development of tourism. A good summary of the history of tourism can be found in Pearce(1972) and a general summary of the history of Mt. Cook in Wilson(1968): thesc references form the basis of this section.

Although the Mt. Cook area was known to the early Maoris there was no settlement; the closest settlement, and not a permanent one, was at the outlet of Lake Pukaki. In the 1850s James Mackenzie opened the route from the Canterbury Plains to the Mackenzie country (for the purpose of sheep-stealing) and it was not until his capture in 1855 that the route to Mt. Cook became known, and permanent settlement began in the area.

In March 1862 Dr. Julius von Haast explored the Tasman and Hooker valleys in the course of geological studies. E. P. Sealy took photographs of the area in 1867 and these photographs were subsequently published in von Haast's book on New Zealand geology. Von Haast and Sealy made further visits in 1869 and 1870. The Governor of New Zealand, Sir George Bowen, on a visit in 1873, asked for a stop to the burning of natural vegetation that was a common management practice of early run-holders of the area. There has been no further intentional burning since his visit.

The Rev. W. S. Green first attempted to climb Mt. Cook in 1882, and, from that time, climbing at Mt. Cook became increasingly popular. To provide for the sportsman five Himalayan thar were introduced in 1904, eight chamois in 1907, and in 1909 three bharal sheep were released but did not survive.

The first attempts to preserve the area for the public were made in 1885 when the Hooker valley was designated a public reserve; two years later the Tasman valley was also designated a reserve. The area was surveyed by Broderick in 1890 and the first maps published in 1891.

In 1884 a hotel (the first Hermitage) was built by F. F. C. Huddlestone near Whitehorse Hill. In 1912 a new Hermitage was started on the site of the present hotel. This work became more necessary when two floods all but destroyed the original building, in January and March 1913. This new Hermitage was opened in January 1914.

There was a major change in the administration of the area in 1953 when the National Parks Act was passed. Four reserves were combined to form the Mt. Cook National Park (the two previously mentioned plus the Murchison and Godley reserves created in 1917 and 1927 respectively).

With increasing pressure on tourist accommodation the Mt. Cook and Southern Lakes Tourist Co., in 1954, made application to build a 60-80 bed motel on Glencoe fan. The Tourist Department rejected the application pending the constitution of the Mt. Cook National Park Board in 1955. The firm made no further application.

In October 1956 control of the Hermitage was transferred from the Tourist Department to the newly-formed

Tourist Hotel Corporation. On the 16th September, 1957, the Hermitage was destroyed by fire but by 30th May, 1958, a new building was opened. This period saw an increase in the amount of accommodation available; the Youth Hostel and fifteen motel units were opened in 1958. In 1962 extensions to the Hermitage were built.

Trans Holdings Ltd. submitted proposals for a 214-bed motel, chalet, and family-unit scheme in May 1965, but after consideration the Park Board recommended that the Tourist Hotel Corporation be granted a licence to build an 80-bed motel unit. This decision was not popular with private tour operators, and in February 1966 the Canterbury Chambers of Commerce, the Canterbury Progress League and the South Island Publicity Association urged the government to increase the accommodation available at Mt. Cook. One suggestion was that the Hermitage area should be lifted out of the National Park and be administered separately for tourism.

In 1968 a ministerial decision was made to provide sites for holiday cottages, more hotels and motels, permanent residences, staff housing, shops and other facilites on a 48ha site at Birch Hill. This decision was modified in favour of the Black Birch fan site; the focus of this study.

In 1972 the Town and Country Planning Division of the Ministry of Works published an approved 25-year, $11.5m plan for the Mt. Cook village (N. Z. MOW 1972) featuring:

i) The building of two quality hotels.

ii) Extension of the existing Glencoe Lodge and Mt. Cook motels.

iii) Construction of a village centre to include shops, cafes, post office, and a tavern or licensed restaurant.

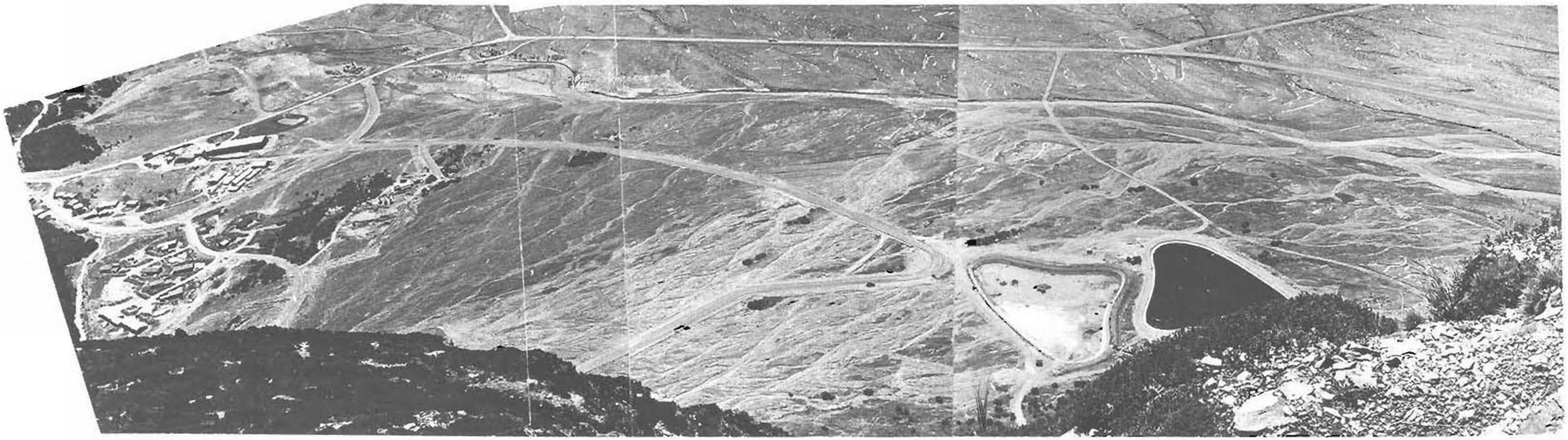
iv) Provision of a day-visitor centre and recreation area, including skating rink, swimming pool and parking areas.

v) Construction of a cableway to the Annette plateau. This proposal has since been abandoned due to economic and technical problems.

In 1973 the Minister of Tourism proposed the construction of cabins and motel accommodation and an eighty-bed extension to the Hermitage. An Environmental Impact Report was released in March 1974 by the Architect's Division of the Tourist Hotel Corporation (N.Z. THC 1974) and approval was given to the proposals.

Building on the fan is not yet complete. Facilities presently on the fan, in the process of construction, or proposed in the near future, consist of staff housing, single men's quarters, workshops, water-storage facilities, sewage ponds, electricity, water and sewage reticulation and roading. Landscaping is being carried out. Fig. 3 shows the state of construction during October 1975.

Fig. 3 Buildings on the Black Birch fan - October 1975. Glencoe Lodge is the large building at the left and below it staff housing and motels can be seen. The curved road marks the position of the sewer leading to the sewage ponds on the right.



2. CLIMATE, VEGETATION & SOILS

2.1 CLIMATE.

Details of the climate of the Black Birch study area are derived from records kept by the New Zealand Meteorological Service. The nearest weather station is at the Hermitage (N.Z. MS no. H30711). These records give a good indication of the weather of the lower parts of the catchment and of the fan, but are probably not accurate for the higher altitudes.

2.1.1 Temperatures.

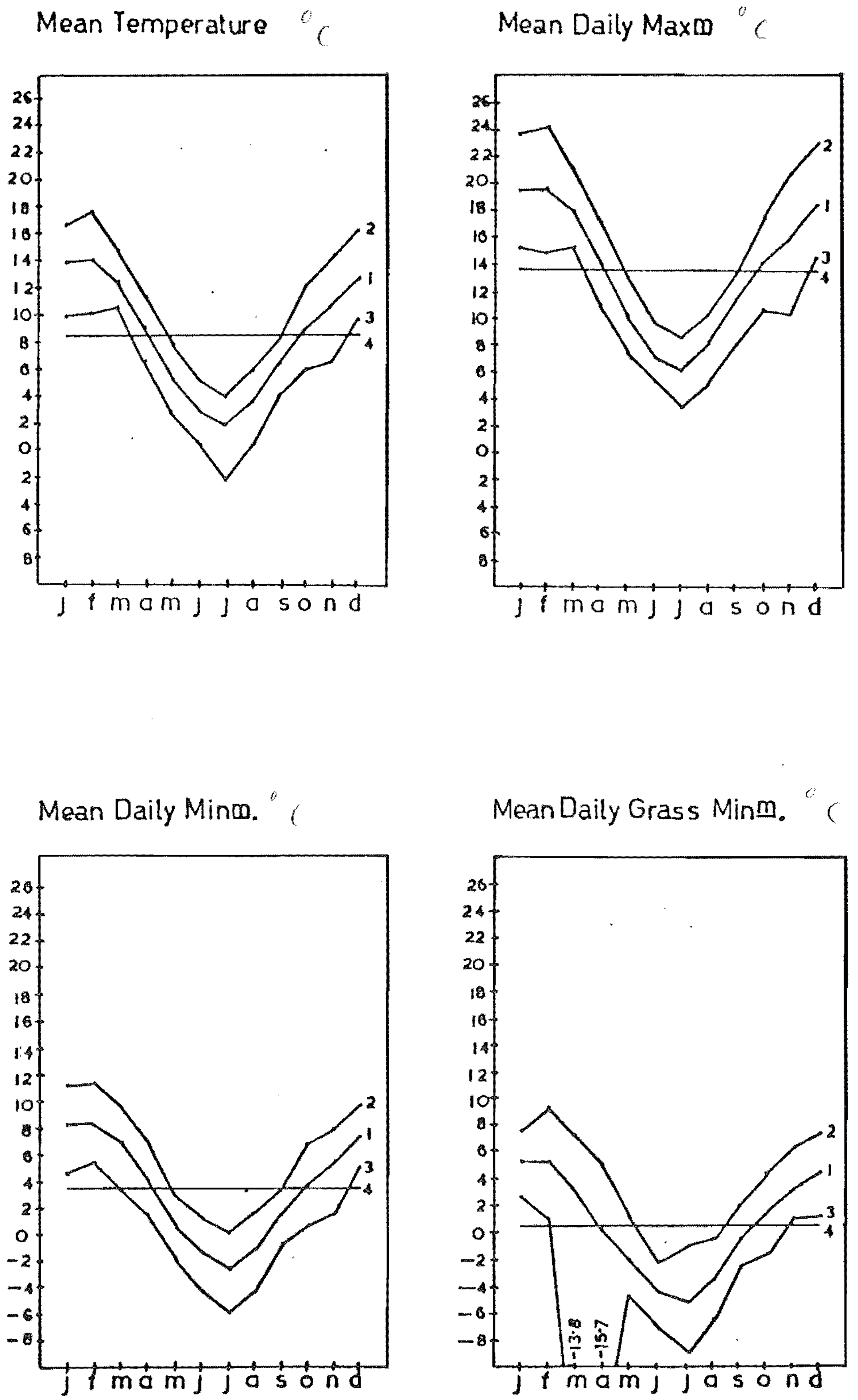
Figs. 4 i-iv show data of mean temperature, mean daily maximum temperature, mean daily minimum temperature, and mean daily grass minimum. Readings are in degrees Celsius.

i) Mean temperature; the values are obtained by averaging the mean daily minimum and mean daily maximum temperatures for each month.

ii) Mean daily maximum: the average of the daily maximum readings for each month. The readings are from thermometers exposed in screens 1.3m above a grassed surface.

iii) Mean daily minimum: the average of the daily minimum readings for each month. The readings are from the same position as ii).

Fig.4 Temperatures recorded at the Hermitage weather station. Data supplied by the N.Z.Meteorological Service.



On the graphs:

line 1 = average monthly reading.
2 = highest average monthly reading.
3 = lowest average monthly reading.
4 = yearly average.

iv) Mean daily grass minimum: the average of the daily minimum readings for each month. Readings are from a thermometer exposed horizontally 2.5 cm above a level grass surface.

In all four figures line 1 refers to the average monthly reading for the period 1930-1974; line 2 refers to the highest monthly average on record; line 3 refers to the lowest monthly average on record; line 4 is the yearly average.

The average number of days each year with a ground frost for the period 1930-1970 is 130.1. The average number of days each year with a frost detected by the screen thermometer for the period 1928-1970 is 96.3.

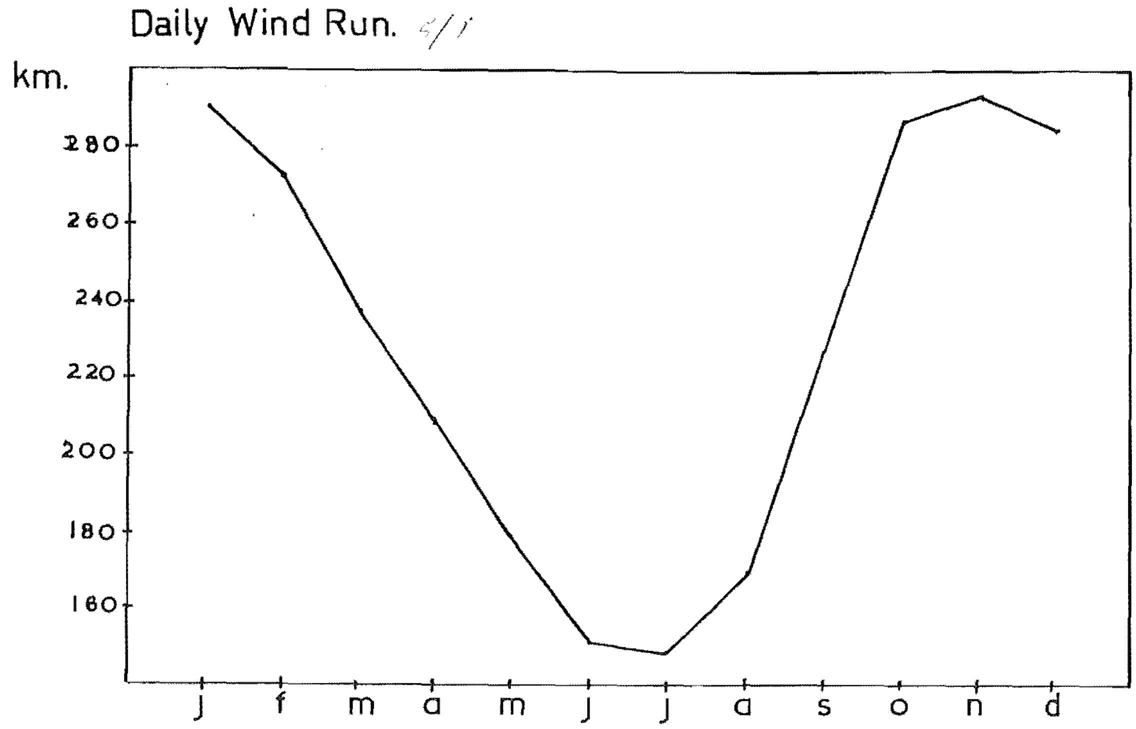
The mean daily range of temperature for the period 1930-1970 is 10.1° C. The greatest range in daily temperature occurs in January and February (11.2°), and the smallest range in July (8.7°).

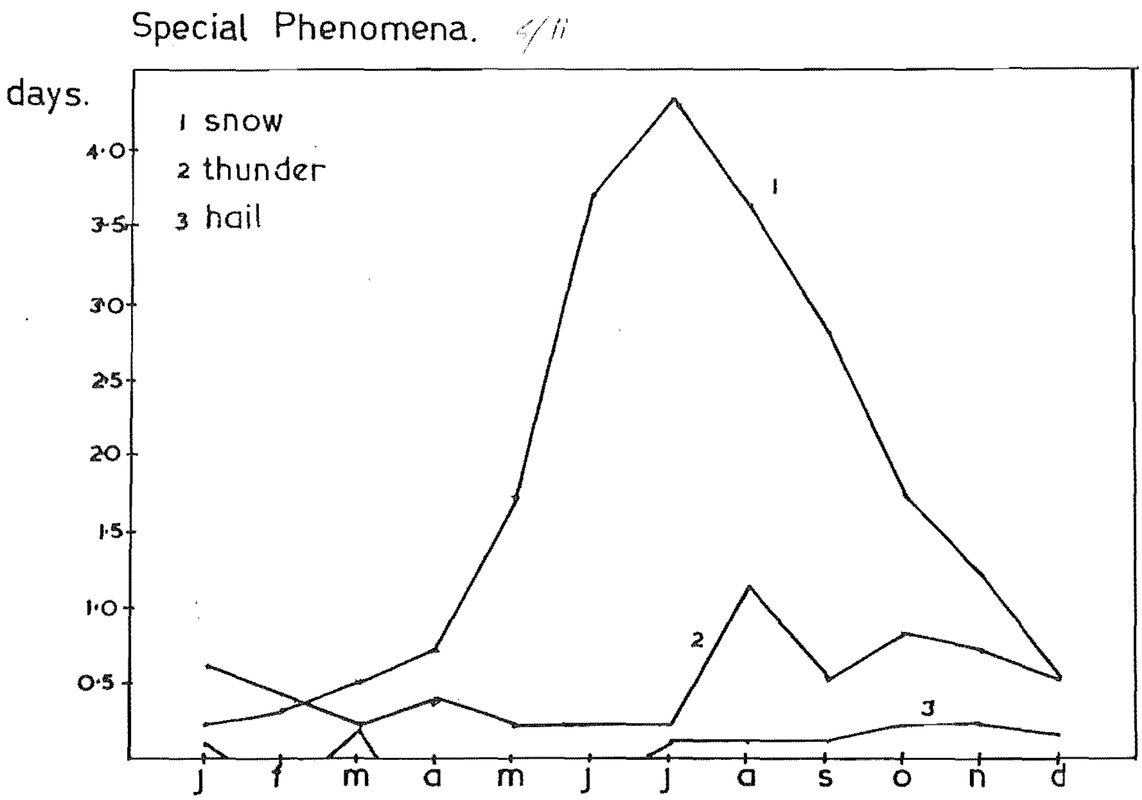
2.1.2 Wind.

Fig. 5 i shows the average daily wind-run in kilometres for the period 1928-1970. The prevailing wind is from the north-west, often associated with rainstorms. Because of the mountainous location, wind direction is unpredictable at low altitudes.

2.1.3 Sunshine.

Fig.5 Average daily wind run and average days per year of snow, thunder and hail. Data supplied by the N.Z.Meteorological Service.





For the period 1935-1970 the yearly average for hours of bright sunshine was 1528, or 35% of possible sunshine hours. This figure may be greater on the Black Birch fan, and on the higher altitude areas of the catchment, because of their more exposed positions compared with that of the weather station.

2.1.4 Special Phenomena.

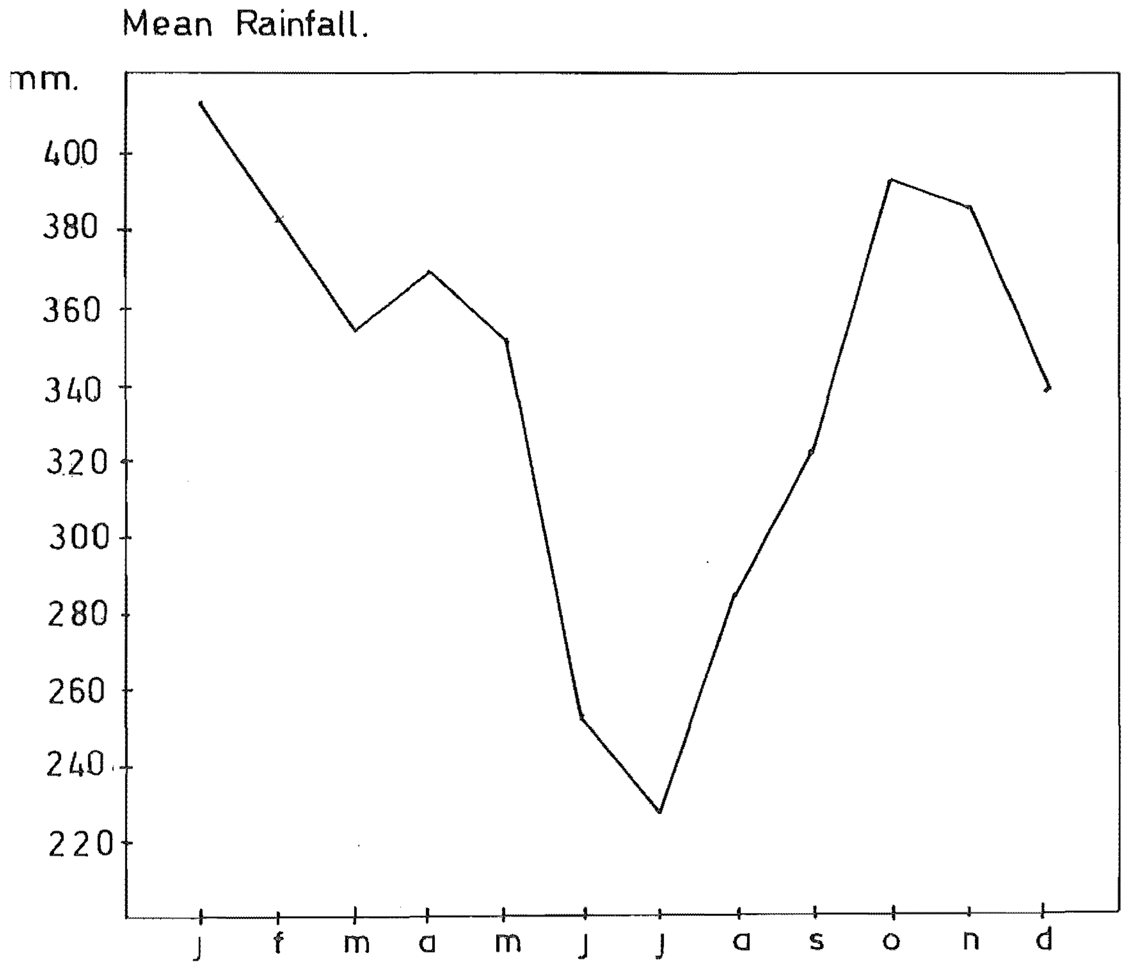
Fig. 5 ii shows the average number of days each month that snow, thunder and hail occurred. For the period 1928-1970 snow fell on an average of 21.1 days each year, hail fell on an average of 1.1 days, and the average number of days with thunder was 5.8. These data probably do not include all occurrences during the hours of darkness.

2.1.5 Rainfall.

There was an average rainfall of 4071mm each year for the period 1930-1970. Fig. 6 shows the monthly average falls. High intensity rainfalls are of particular importance to this study; they generally last from 12 to 48 hours and are associated with north-west winds. They are particularly common during the summer months.

2.1.6 Depth-Duration Records.

Fig.6 Mean monthly rainfall recorded at the Hermitage weather station. Data supplied by the N.Z. Meteorological Service.



The only depth-duration (intensity) records from the Mt. Cook area are maximum 24-hour rainfalls for each month. Incomplete records for the period 1928-1974 were obtained from the N. Z. Meteorological Service. These records can be analysed statistically to give an indication of the frequency of occurrence of various rainfall intensities, and this information constitutes a basic input into later hydrological calculations.

The most common method of analysing depth-duration data is to assign to each depth-duration value a return period (T), which is the probability of that depth-duration being equalled or exceeded in a specified period of time. The statistical methods and the results obtained are outlined in appendix 1, and fig. 7 shows the resultant graph of rainfall depth against return period.

2.2 VEGETATION

Because of the large range in altitude, slope steepness, and aspect, vegetation shows a wide range of vertical and lateral variation. Above approximately 1365m the area is almost devoid of vegetation except for lichens and ground-cover herbs. Tussock, mountain totara (*Podocarpus nivalis*), celery pine (*Phyllocladus alpinus*), and varieties of *Olearia*, *Hebe* and *Dracophyllum* are common in areas below 1365m and above 760m especially on the north-facing slopes. These areas also

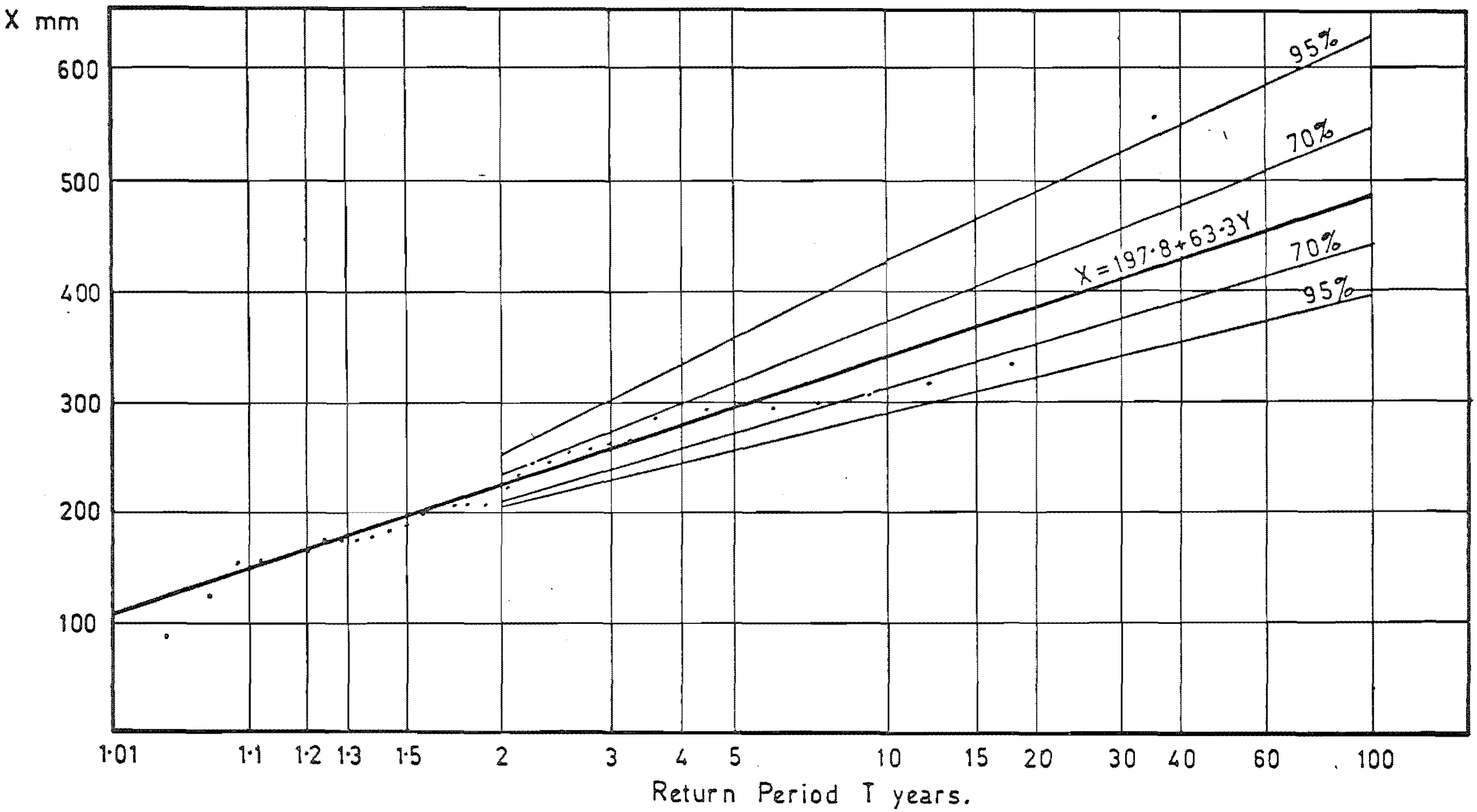


Fig.7 24-hour rainfall vs. return period. See appendix 1 for derivation and explanation.

contain the Mount Cook Lily (Ranunculus lyallii) and the mountain daisy (Celmisia coriacea).

On shadier south-facing slopes between 1365 m and 760m beech (Nothofagus sp.), broadleaf (Griselina lucida), Hebe and mountain ribbonwood (Gaya lyallii) form the nucleus of an alpine forest community.

Below 760m the vegetation is dependent on the age of the land surfaces; the older, more stable areas, are characterised by tussocks, browntop and other introduced grasses, and matagouri (Discaria toumatou). The younger areas are characterised by tussock, browntop and low shrubs. Recently-active areas may be completely bare or have a variety of mosses, lichens and some low herbaceous plants.

There are two areas of specialised bog communities around the mountain tarns on the slopes of Mt. Sebastopol.

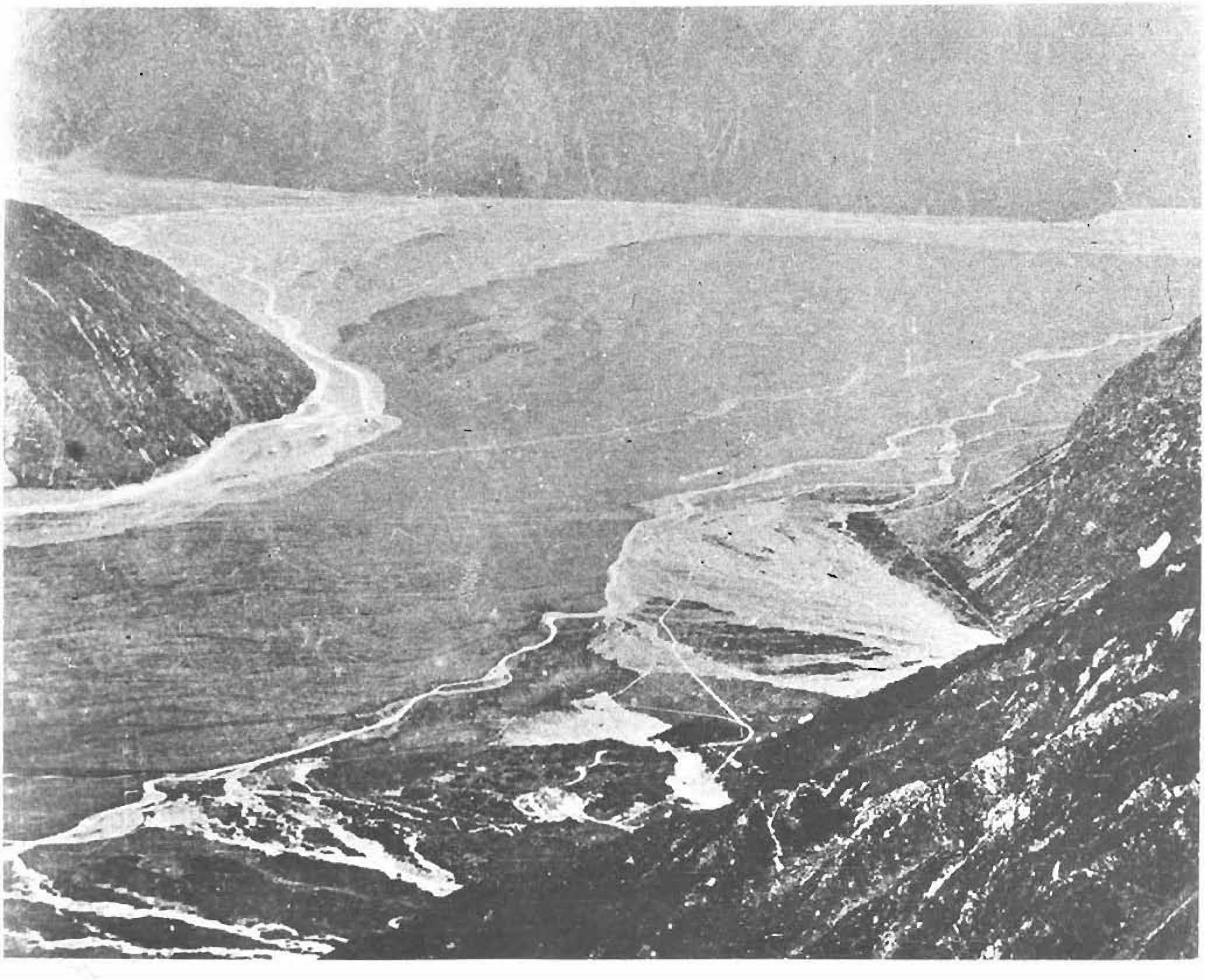
Changes in vegetation composition and type may have occurred in the Black Birch catchment over the past few hundred years and more especially since European settlement in the area. Molloy et. al (1963) report discoveries of beech and podocarp charcoal on the western shores of Lake Pukaki and attribute these to fires in the pre-European era. Burnt stumps, probably of beech, were found above a small stand of existing beech near Sawyers stream during the course of field work and these could be attributed to burning by the early runholders of the area. An area of fallen and burnt tree trunks was found in the Black Birch catchment and on the south side of the catchment an area with a charcoal layer 8-10cm below the surface was discovered. This was previously unknown, although a charcoal layer under Governor's Bush slightly to the west has been studied (M. Heine, pers. comm.). The catchment may have been grazed by sheep until fairly recently although no records could be found to determine when this ended. Vegetation modification would have followed the introduction of thar to the area in 1904 and chamois in 1907. Local residents report that a herd of thar lived in the catchment until a few years ago. Hares are still quite common in the area.

Changes to the vegetation in the stream channel and on the fan surface can be seen by comparing early photographs of the area, and in most cases it appears that vegetation has been removed or buried (fig. 8) Increased sediment loads and higher flood flows as a result of damage to vegetation in the catchment may be the cause of this apparent reduction in vegetation on the fan surface.

2.3 SOILS

Soils are generally poorly developed and are formed over colluvium and glacial deposits within the catchment, and over fluvial deposits in the Hooker valley. The source material is in general greywacke; the occurrence of schist in the glacial deposits appears to have no significant effect on soil development or type.

Fig. 8 Black Birch fan c. 1927-28. Changes in the distribution of vegetation can be seen by comparison with fig. 14. Photograph by courtesy of the Mt. Cook National Park Board.

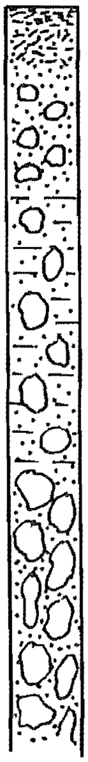


Three soil types were observed in the field, and these correlate with the three altitudinal zones of vegetation mentioned above, and with those mentioned in the N. Z. Soil Bureau Bulletin No. 27 (1968). Above 1365m the soils are described as "Alpine Steepland Soils, reference no. 100, Alpine Steepland Soils"; between 1365m and 760m as "Upland and High Country Podzolised Yellow-Brown Earths and Podzols, reference no. 65, Lewis Steepland Soils"; below 760m. as "Recent Soils, reference no. 99, Tasman Soils". Representative profiles for the Lewis and Tasman soils are shown in graphic form in fig. 9. In general these profiles agree with field observations.

The Lewis soils are particularly susceptible to erosion especially if the vegetation is removed or damaged; this erosion is the result of the combined forces of overland flow, needle ice and probably to some extent wind erosion.

Fig.9 Graphic soil profiles of the Lewis and Tasman soils. Derived from the N.Z. Soil Bureau 1968.

LEWIS.



0.6cm Loose discontinuous surface litter.

2.5cm Very dark brown granular peaty-loam; spongy.

7.5cm Pale grey-brown crumb/single grain stony silty-loam; friable.

23cm Brown-yellow mottled red-brown nutty silty loam with stones; firm.

Fragmented greywacke in yellow-brown matrix

TASMAN.

20cm Very dark brown granular/crumb silty loam; very friable.

23cm Sand and gravel with dark brown staining; loose.

Dark brown structureless loamy-silt merging to loose sandy gravel.

3. GEOLOGY.

3.1 REGIONAL GEOLOGY.

The Black Birch study area is within the Torlesse Group of greywackes, argillites and their metamorphic equivalents, which are believed to have been laid down in Permian to Jurassic times. These are metamorphosed to the prehenite-pumpellyite facies and are assumed to grade down into low-temperature-high-pressure schists. The Torlesse Group rocks are thought to have been deposited as turbidites within a geosyncline; field indications of the interbedded greywackes and argillites tend to support the turbidite origin, although no definitive studies have been carried out in the immediate area. Fossil localitites have been reported in the larger region (Lillie and Gunn 1964, Campbell and Warren 1965) but none have been found in the Black Birch catchment.

During the later stages of geosynclinal deposition and following the apparent conclusion of deposition in the Jurassic, tectonic movement on a large scale occurred; this is known as the Rangitata Orogeny. In the Mt. Cook region the orogeny was responsible for the major faults and folds including the Alpine Fault, and uplift of the New Zealand land surface in general. Movements associated with the orogeny are believed to have ended in the middle Cretaceous.

Kaikoura more [illegible]

A period of tectonic stability and apparent peneplanation followed until the Kaikoura Orogeny of Miocene-

Recent age resulted in uplift, and probably more faulting and folding, in the Mt. Cook region. This movement probably continues today. During the period of the orogeny the area has been subjected to glaciation so that the present day landscape reflects the complex structure followed by modification by glaciation.

Much has been written about the geology of the Mt. Cook area; a bibliography is included in the appendices and also a bibliography of the glacial history of the area.

3.2 GEOLOGY OF THE STUDY AREA.

3.2.1 Structure.

A comprehensive outline of the structure of the Black Birch study area is contained in a paper by Lillie and Gunn (1964). This paper serves as the basis for this section, supplemented by field study and air photo interpretation. Map 2 shows an outline of the geology of the study area.

The major structural features trend north-south, the most outstanding feature being the Great Groove fault which divides the catchment area in two. To the east of this line there is folded and faulted greywacke, while to the west there is a more complex structure of schists and greywacke.

Interbedded greywacke and argillite to the east of the Great Groove fault strike at approximately 80^{o}-90^{o}

not on map.
all strike about North

and generally dip steeply. Observations of younging direction and dip direction suggest an anticline with the fold axis running through Mt. Sebastopol. From the Mt. Sebastopol anticline towards the Great Groove fault Lillie and Gunn (1964) suggest several faults parallel to bedding and another anticline with a limb abutting the Great Groove fault.

East of Mt. Sebastopol a fault runs north-south and causes a change in bedding strike. This fault was observed in one place to be an intensely fractured and crushed zone of considerable width. Its continuation is inferred from the change in slope and the change in the strike of the bedding, and it appears to cross the Black Birch Stream at the upstream opening of the gorge.

The Great Groove fault strikes approximately north-south and dips steeply to the west. From air photos, and in the field, it can be seen clearly from a distance (Fig. 10). Its exposure in the Black Birch stream bed shows as a zone of fractured argillite, intensely veined with quartz, releasing quantities of water, and in places stained with iron oxides. No one plane of movement can be defined. On the ridges to both Annette and Kitchener the fault causes cols and offsets of the ridge-lines. The stream channel is also offset.

West of the Great Groove fault schist is found. Near the fault zone the schist is green in colour, cleavage is parallel to bedding, and mineral segregation in places is quite clear. Further west the schist shows fewer characteristic structures, but Lillie, Gunn and Robinson (1957) state that schistocity increases towards

Fig. 10 The Great Groove fault on the south side of the Black Birch catchment. The fault line runs from the centre foreground to the left background. Several landslides are formed along the fault line. Greywacke and argillite to the left of the fault, schist to the right.

the second major fault, the Green Rock fault, in the following way;

i) Sub-schists with lineation down dip.

ii) Sheared hard siliceous sandstone.

iii) Purple shales.

iv) Hard green rock in lenses (up to 1m thick).

v) Purple sheared rocks with green streaks.

vi) Massive siliceous sandstone with thin layers of phyllite and quartz veins.

The Green Rock fault is reported by Lillie and Gunn (1964) to be parallel to bedding, and like the Great Groove fault, it is a zone of movement rather than a single plane of movement. The Green Rock fault zone abuts the eastern overturned limb of the Kitchener anticline. The Kitchener anticline trends north-south and plunges to the north at about 30°. The eastern limb is overturned to dip 70°-80° to the west, and the axis of the anticline runs slightly to the west of the western boundary of the Black Birch catchment.

3.2.2 Lithology.

Greywacke is a common term used to define the coarse-to-fine arkosic sandstone found in the area. Beds of this material are interbedded with argillite, which is the siltstone equivalent to the greywacke. In general the argillite beds are thinner (a few centimetres) than the greywacke beds (up to several metres); considerable variation occurs. The interbedded greywackes and argillites are strongly indurated and jointed. Some sedimentary structures occur in the greywacke, especially graded bedding.

According to Lillie and Gunn (1964) "petrographically the greywackes belong to the prehnite-pumpellyite mineral facies described by Coombs (1960)." They note that while the majority of the greywackes were characterised by unaltered potash feldspar, towards the Great Groove and the Green Rock Fault zones, the potash becomes sericitised and accompanies the appearance of some schistose structures.

The schists appear to be the metamorphic equivalents of the greywackes. They are generally classified as belonging to the chlorite 2 and in places the chlorite 3 subzones. Lillie and Gunn (1964) classify the rocks to the east of the Green Rock fault zone as greenschists, and suggest that these are probably layers of altered basic tuffs within the Torlesse Group of rocks.

3.3 GLACIAL GEOLOGY.

3.3.1 Glacial History.

Present day glaciers in the Mt. Cook area are the most obvious indicators of past glacial action. Pleistocene glaciers caused the excavation of the major valley systems in the area, and periodic advances and retreats have deposited a variety of forms of moraine within these valleys.

The Hooker valley, in which the Black Birch fan has been formed, is a typical "U" shaped valley, partially filled with outwash, so that in its present form it is a steep sided trench with a flat bottom. The Tasman valley also has this form.

Within the Hooker valley, the general absence of lateral moraines on the sides of the valleys makes the earlier glacial history hard to interpret. Discontinuous terrace deposits do occur on the southern slopes of Mt. Wakefield and one of these terraces has a level closely equivalent to the level on the top of the Sebastopol buttress. These terraces have depressions on the top surface which may from time to time hold water. The terraces are indicative of several glacial advances and retreats, although the relative ages of these are not known. Terminal moraines to the west of Black Birch stream give an indication of glacial history in more recent times. The oldest moraine in the White-horse hill area has been dated at 530 years B. P. by Lawrence and Lawrence (1965).

Gair (1967) mentions two dates for the moraines in the Tasman valley to the south of the Hooker valley junction as 5,120 and 8,460 years B. P. These two dates are from moraines of the Birch Hill Formation named by McGregor (1967) (the first date is from the type area, and the second from the Macaulay river behind Lake Tekapo). In general the extent of this formation agrees with the Birch Hill Landform Association of Speight (1963).

Speight (1963) defines the Birch Hill Landform Association as the area south of "a moraine-strewn shoulder at 4,000ft on Mt. Sebastopol. . .".

The Birch Hill Formation resulted from the last major advance of the Tasman glacier past the junction with the Hooker valley, and it may therefore be inferred that glacier ice filled the Tasman valley and probably the Hooker valley until at least 5,120 years B. P.

While few glacial deposition features are found on the walls of the Hooker valley, deposits of fluvioglacial materials with a vertical thickness of at least 150 m are found in the Black Birch stream catchment.

The time interval between the deposition of the Birch Hill Formation and the present is 5,120 years; thus, within this maximum limit, features such as the downcutting of 150m of glacial deposits and the formation of the Black Birch fan occurred. The same period of time may represent the maximum time taken for the Great Groove fault to offset the stream and the ridges within the Black Birch catchment.

3.3.2 Glacial deposits.

Extensive stratified deposits of glacial or proglacial origin occur within the Black Birch catchment, in particular on the south side (fig. 11). A slight break in slope and a change in the nature of erosion features are the best indicators of the extent of these deposits. This material is probably the northern exten-

Fig. 11 Glacial deposits on the south side of the catchment. Black Birch stream in the right foreground. The horizontal line about two-thirds up the photograph marks the boundary between the colluvium (top) and the glacial deposits (bottom). A distinct change in landform along the boundary can be seen. The V-shaped landslide above the boundary is a debris avalanche.

sion of material associated with the Birch Hill Landform Association of Speight (1963) and of the Birch Hill Formation of McGregor (1967); however in neither paper was the material in tributary valleys to the north and west of Mt. Sebastopol examined or described.

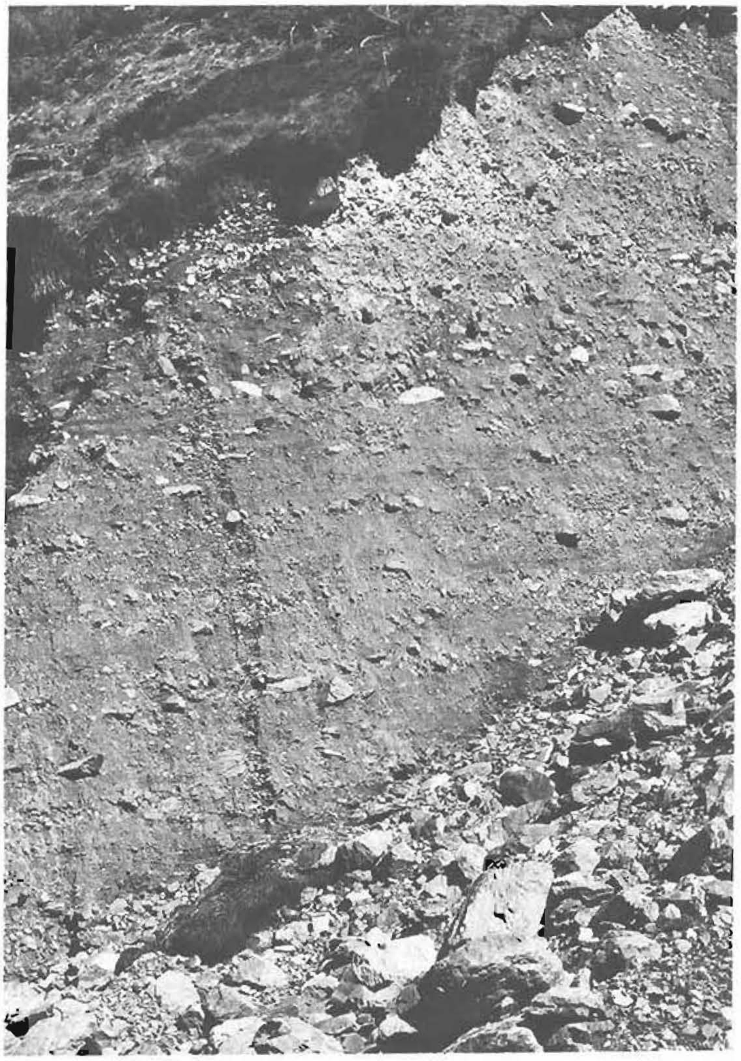
Speight (1963) defines moraines of his landform association as having an elevation of 4,000ft (1,213m) on the shoulder of Mt. Sebastopol; that is in the area of the tarns above the Sebastopol buttress. The elevation of the glacial deposits in the Black Birch catchment is, however, about 1,060m and the deposits are more or less continuous in level on the south side of the catchment (this level is defined by the Red Lakes). Because of the difference in elevation between the two features, the material in the catchment is probably the outwash of a valley glacier that at some earlier time contributed to the formation of the moraines at the 1,213m level.

The nature of the particles within the deposits suggests the fluvio-glacial nature of the deposits, because of the consistent rounding of the larger particles and the lack of striations on their surfaces. These features differentiate between outwash gravels and deposits of similar morphology called "kame terraces".

Although the deposits are stratified, the stratification is not continuous or systematic; lateral variations of particle-size and degree of sorting are as frequent as vertical variations (fig. 12) Layers of clean sands showing graded bedding contrast with deposits best

Fig. 12 i) Glacial deposits on the south side of the catchment along a tributary stream. The section is 15-20m thick. Sub-horizontal stratification and poorly-sorted deposits can be seen.

ii) Detail of glacial deposits. The range of particle-sizes and slight rounding of the particles is shown. The larger particles have longest axes of about 1m.



described by the now obsolete term "boulder clay" (deposits of boulders in a stiff clay matrix) and layers showing a complete size-range of unsorted particles. Within the deposits erratic blocks, several metres in diameter are found, but most of the boulders have diameters of less than 2m. These boulders are of both greywacke and schist with greywacke predominating and most show some degree of rounding, so that most are at least sub-angular. In the boulder-to-sand fraction, and the sand fraction itself, there is also a variety of lithology and rounding, but this size range is in general more rounded than the boulder fraction.

Below the sand-sizes there is apparently a predominance of silt which gives the material a low plasticity. Four samples from different levels in the deposits were collected and material smaller than 4ø (o.0625mm) was sieved out and dried. Simple soils-engineering tests of dilatancy, toughness, dry strength, and shine were carried out. All four samples gave similar results. The results of the tests were:

i) Dilatancy. A measure of the mobility of the pore water; the reaction of the samples was quick, indicating high mobility and therefore the presence of low plasticity silts and clays.

ii) Toughness. A measure of the consistency near the plastic limit; the reaction of the samples was slight, indicating that there is no significant clay mineral content.

iii) Dry strength. A measure of the plasticity of the sample and, as a consequence, the clay mineral content; the samples gave a slight-to-medium reaction indicating low plasticity.

iv) Shine. A measure of the plasticity and silt or clay mineral content; samples had a dull shine indicating low plasticity and the presence of silt or non-plastic clays.

As a mass the deposits appeared grey on the surface and also appeared to be unconsolidated; this is due to the presence of mainly greywacke particles adhering to the weathered surface. When the weathering layer was removed the deposits appeared as a yellow, highly compact mass. To extract samples, it was necessary to use the pick of a geological hammer to loosen the material, some force being required to make an impression. Except for layers or lenses of sand the material was water-saturated, and the matrix rapidly became "quick" in disturbed samples. In one place a spring emerges from a steep gully face and this would appear to be the result of a sand layer acting as a filter-bed for the surrounding material.

Several sources report that silt material is susceptible to frost-heave, and the deposits in the Black Birch catchment are no exception. Needle-ice developed after quite light frosts; the erosive effect of this process is probably enhanced by subsequent wind action which removes the material loosened by the ice.

The deposits are in general fresh and, when washed, the larger greywacke particles show few signs of staining or chemical weathering. The schist particles tend to fracture readily along planes of weakness and also have a white colour as a result of chemical weathering of the micas along the cleavage planes.

In terms of the N. Z. Geological Survey Soils Classification Chart the material is a coarse-grained soil containing more than 50% of particles larger than 200 mesh B. S. sieve (0.074mm), and more than 50% of the coarse fraction is larger than 2mm. The gravels are dirty, containing appreciable amounts of non-plastic fines. The group symbol is "GM" and the group name is "Gravel, excess silty fines". Because of the size of the largest particle representative sampling was impossible and consequently no grain size curve is possible.

3.4 SCREES.

Screes cover large areas of the higher parts of the catchment but they are not well developed on the areas of schist. Surface slopes of 30°-35° are common. The material shows a variation in size from place to place on a scree in both vertical and lateral directions. In the vertical direction the particles are larger near the base of the scree due to the greater momentum of the larger particles when in motion. In the lateral direction the size variation appears to be directly related to the intensity of jointing in the rock supplying the material to the section of the scree.

In general the particles are larger than 2cm in diameter except within a few metres of the source rocks (fig. 13). On lower reaches of the screes fines are uncommon. Sphericity (a measure of the relative lengths of the three main axes) is also variable depending on the intensity of jointing in the source rocks; in general the particles have a compact to elongate form. Roundness (the curvature of the sharpest corner) is low, although corners do tend to be worn due to impacts during movement and slight amounts of chemical weathering.

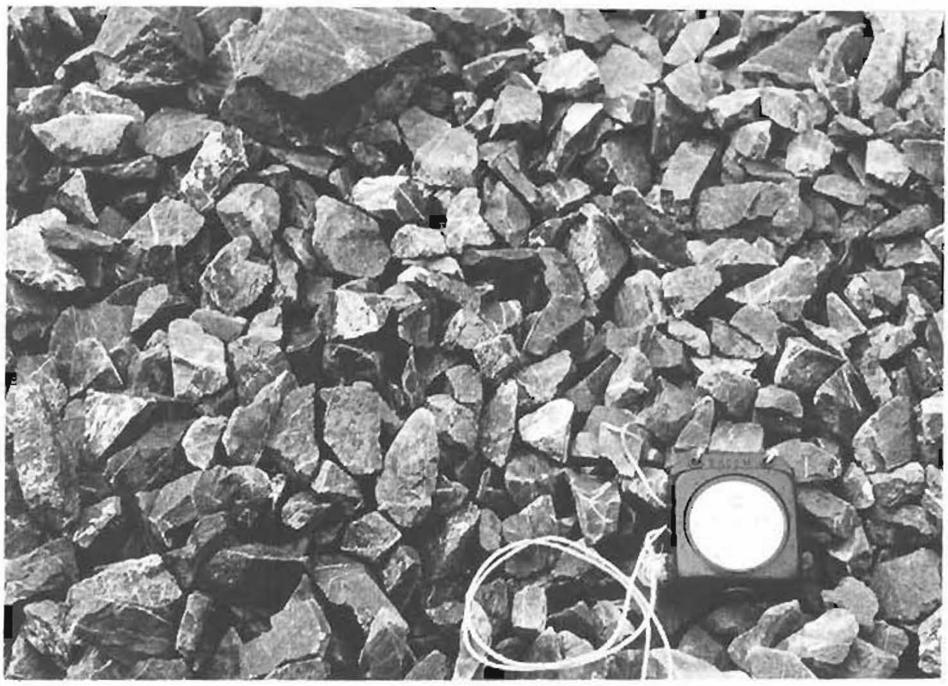
Both active and inactive screes are present within the catchment; the activity can be judged from the quantity of vegetation, both of higher plants and of lichens on the screes. Scree activity may be associated with avalanches, since in winter it was noted that avalanches frequently develop in the rocks above a scree and terminate near the base of the scree slope. Caine (1969) suggests this mechanism for scree development in the Two Thumb Range in the Rangitata headwaters.

3.5 THE BLACK BIRCH FAN

A choice of two methods of study of the fan was available. A study of the sediment size, shape and sorting by methods commonly used by sedimentologists would describe the sedimentary environment and the

Fig. 13 i) Scree deposits below Mt. Sebastopol. An area of disturbed scree to the left probably marks the terminal of a recent avalanche.

ii) Detail of scree deposits. The lack of fines and of rounding of the particles is noticeable. The altimeter is 6cm x 6 cm.



variations within that environment. A method of study that gives information on the dynamics of formation is more applicable, and of greater consequence to engineering works on the fan.

3.5.1 Tractive-Force Studies.

A) Theory. A study of the dynamics of processes on a fan-surface was made by Lustig (1965). The theory and method used in this study is based on his paper.

The size of sediment found on the fan-surface is related to the competence of the transporting medium and to the nature of the source area supplying the materials to this medium. The competence of a stream is defined as "the maximum size of particles of given specific gravity, which at a given velocity, the stream will move" (American Geological Institute Glossary of Geology and Related Sciences).

If all the particles in a stream have an identical specific gravity and the velocity of flow of the stream is constant, then the sizes of the particles that can be transported depends on the depth of flow. If the specific gravity of the particles is constant then the competency is a function of the velocity and depth of flow. The shear force exerted on the upper layer of the bed-load is therefore dependent on the velocity and depth of flow. The shear force is called the tractive-force.

In an existing stream the depth of flow and the velocity can be measured, but on a fan surface only the deposits resulting from a flow can be observed, and from these the velocity and depth of flow must be calculated.

If the assumption is made that particles will not move unless they are totally covered by water, and that in the source area there is a range of particle sizes so that the largest particles found on the fan surface are the maximum transportable size under the particular flow conditions, then the size of the particles bears some relation to the depth of flow. Since it is unlikely that particles will move with their longest axis in a vertical plane, and that it is likely that they will move with their intermediate or shortest axis in that plane, then the depth of water can be represented by the intermediate axis length of the largest particles on the fan surface.

The velocity of flow is controlled by the specific weight of water and the gradient of the water surface. The specific weight can be defined by the following equation:

$$y = pg$$

where y = specific weight of water.

p = density of water.

g = gravitational acceleration.

The gravitational acceleration is dependent on the gradient through which it acts; that is approximately the gradient of the water surface. If it is assumed that for each flood event the temperature of the water and quantity of suspended sediment remains constant (i. e. the density remains constant) then the parameter controlling velocity is the gravitational acceleration, and that, by definition is dependent on the slope of the water surface. The slope of the bed is a close approximation of the slope of the water surface; therefore the velocity of flow is proportional to the slope of the bed.

In summary:

$$\tau = ydS$$

where τ = tractive-force.

y = specific weight of water.

d = depth of flow.

S = slope of the energy gradient (approximately the slope of the water surface).

But if the density of the transporting medium is assumed to be constant then:

$$\tau \propto dS$$

and $d \propto$ length of the intermediate axes of the largest particles found on the fan surface.

$S \propto$ slope of the stream bed on the fan-surface.

The varying energy conditions represented on the fan-surface are computed using values of dS which give results proportional in some way to the tractive-force.

B) Field Methods. Sampling of the largest particles and slopes on the fan surface could have been carried out in a number of ways, but the most convenient method was along levelled traverses; this enabled the positions to be identified on maps of the fan. The traverses were levelled from features that could easily be identified on the maps. Care was taken to avoid areas of disturbed ground.

Four traverses were laid out at approximate elevations 710m, 715m, 722m, and 730m using an engineering level, and sampling stations were marked at about 30m intervals along these traverses. The position of each station is marked on fig. 14. A total of 55 stations was used. At each station the longest, shortest and intermediate axis of the largest particle within a 5m radius was measured, lithology was noted, and five measurements of the ground slope over a distance of 2m were made. The slope measurements were taken in the apparent direction of particle movement.

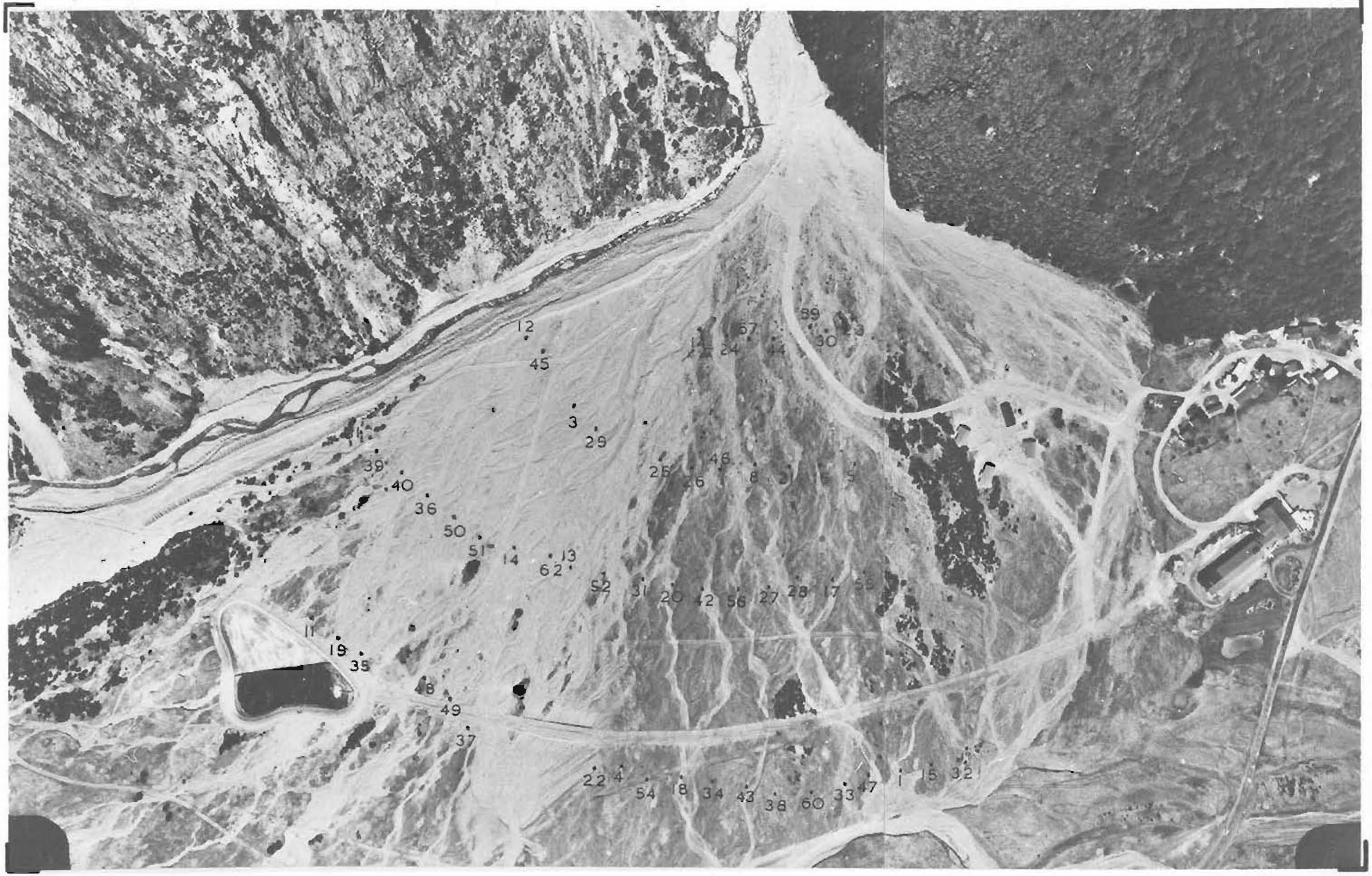
C) Results. Columns i)-v) in table 1 record:

i) The station number.

ii) The length in metres of the longest, intermediate, and shortest axis.

iii) The average of the five slope measurements in degrees.

Fig. 14 Position of the sampling stations on the Black Birch fan. The base photograph is an uncorrected photo-mosaic derived from photos A/4 and A/5 of run 3596.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32

Table 1 Tractive-force data.

i) Stn.no	ii) Axis length m			iii) Slope	iv) Slope m/m	v) dS	vi) Mean diam	vii) Lith.
GS32	.37	.23	.20	1.6	.0279	.006	.267	gwk
GS15	.17	.16	.13	4.2	.0729	.012	.153	gwk
GS01	.41	.16	.15	3.9	.0670	.011	.240	gwk
GS47	.37	.19	.14	3.6	.0641	.012	.233	sch
GS33	.51	.36	.31	4.0	.0699	.025	.427	gwk
GS60	.39	.30	.23	3.6	.0641	.019	.307	gwk
GS38	.50	.23	.18	3.6	.0641	.015	.303	gwk
GS43	.66	.37	.33	2.6	.0466	.017	.453	gwk
GS34	.50	.38	.25	2.0	.0350	.013	.377	sch
GS18	.35	.30	.22	4.4	.0758	.027	.290	gwk
GS54	.51	.23	.22	3.9	.0670	.015	.320	gwk
GS04	.33	.23	.20	4.0	.0699	.016	.253	gwk
GS22	.55	.21	.20	6.4	.1139	.024	.320	gwk
GS37	.40	.28	.16	3.6	.0641	.018	.280	gwk
GS49	.46	.26	.23	4.2	.0729	.019	.317	gwk
GS48	.36	.24	.13	5.0	.0875	.021	.243	gwk
GS35	.39	.20	.18	3.6	.0641	.013	.257	gwk
GS19	.28	.19	.12	2.8	.0495	.009	.197	gwk
GS11	.37	.19	.17	4.6	.0816	.016	.243	gwk
GS55	.54	.28	.24	4.6	.0816	.023	.353	gwk
GS17	.58	.42	.38	5.8	.1022	.043	.460	gwk
GS28	.62	.43	.30	5.4	.0963	.041	.450	gwk
GS27	.50	.33	.28	4.2	.0729	.024	.370	gwk
GS56	.55	.26	.21	6.8	.1198	.031	.340	gwk
GS42	.40	.30	.27	4.6	.0816	.024	.323	gwk
GS20	.70	.25	.20	4.2	.0729	.018	.383	gwk
GS31	.26	.16	.10	5.0	.0875	.014	.173	gwk
GS52	.48	.26	.20	4.6	.0816	.021	.313	gwk
GS13	.42	.30	.16	4.2	.0729	.022	.293	sch
GS62	.58	.32	.24	6.6	.1169	.037	.380	gwk
GS14	.38	.37	.36	3.2	.0553	.020	.370	sch
GS51	.45	.36	.28	4.6	.0816	.029	.363	gwk
GS50	.44	.36	.22	3.2	.0553	.020	.340	gwk
GS36	.48	.32	.19	3.0	.0524	.017	.330	gwk
GS40	.32	.26	.22	3.4	.0612	.016	.267	gwk
GS39	.43	.19	.16	4.6	.0816	.016	.260	sch
GS61	.31	.26	.22	5.4	.0963	.025	.263	sch
GS05	.50	.44	.21	7.6	.1346	.059	.383	gwk
GS16	.60	.48	.30	5.4	.0963	.046	.460	gwk
GS21	.68	.50	.40	6.4	.1139	.057	.527	gwk
GS08	.38	.32	.31	5.0	.0875	.028	.337	gwk
GS46	.73	.44	.32	4.6	.0816	.036	.497	gwk
GS26	.64	.32	.22	6.6	.1169	.037	.393	sch
GS25	.56	.32	.18	4.8	.0846	.027	.353	gwk
GS29	.76	.42	.32	5.8	.1022	.043	.500	gwk
GS03	.55	.31	.30	7.0	.1228	.038	.387	gwk
GS45	.58	.37	.26	5.2	.0904	.033	.403	sch
GS12	1.0	.80	.40	4.8	.0846	.068	.733	gwk
GS23	.45	.37	.27	5.6	.0992	.037	.363	gwk
GS30	.54	.29	.18	8.2	.1435	.042	.337	sch
GS59	.84	.57	.35	5.5	.0992	.057	.587	sch
GS44	.62	.46	.32	3.0	.0524	.024	.467	gwk
GS57	.82	.43	.27	5.2	.0904	.039	.507	gwk
GS24	.47	.43	.34	5.0	.0875	.038	.413	gwk
GS14	.68	.52	.30	6.0	.1051	.055	.500	sch

iv) The average slope expressed in metres fall per metre.

v) The dS product.

Table 1 column vii) records the lithology.

Contours of the dS products are drawn on fig. 15. The contours are drawn to coincide, as much as possible, with features on the fan; straight contour segments follow the general direction of identifiable stream channels on the fan surface.

The mean values and standard deviations of the dS products for each traverse were calculated, and the means compared using Student's "t" test; the results are tabulated in table 2. There is a significant difference between the mean dS products of the 710m and 715m traverses and of the 715m and 722m traverses. There is no significant difference between the mean dS products of the 722m and 730m traverses. Therefore there is a significant decrease in dS products down-fan from the 722m traverse to the 710m traverse. Above the 722m traverse the results are inconclusive: there may be no significant difference between the mean dS products of the 722m and 730m traverses, or there could be a difference that is not identifiable because there were too few samples along the 730m traverse. The latter conclusion is more probable.

Fig. 15 Contours of equal dS products.

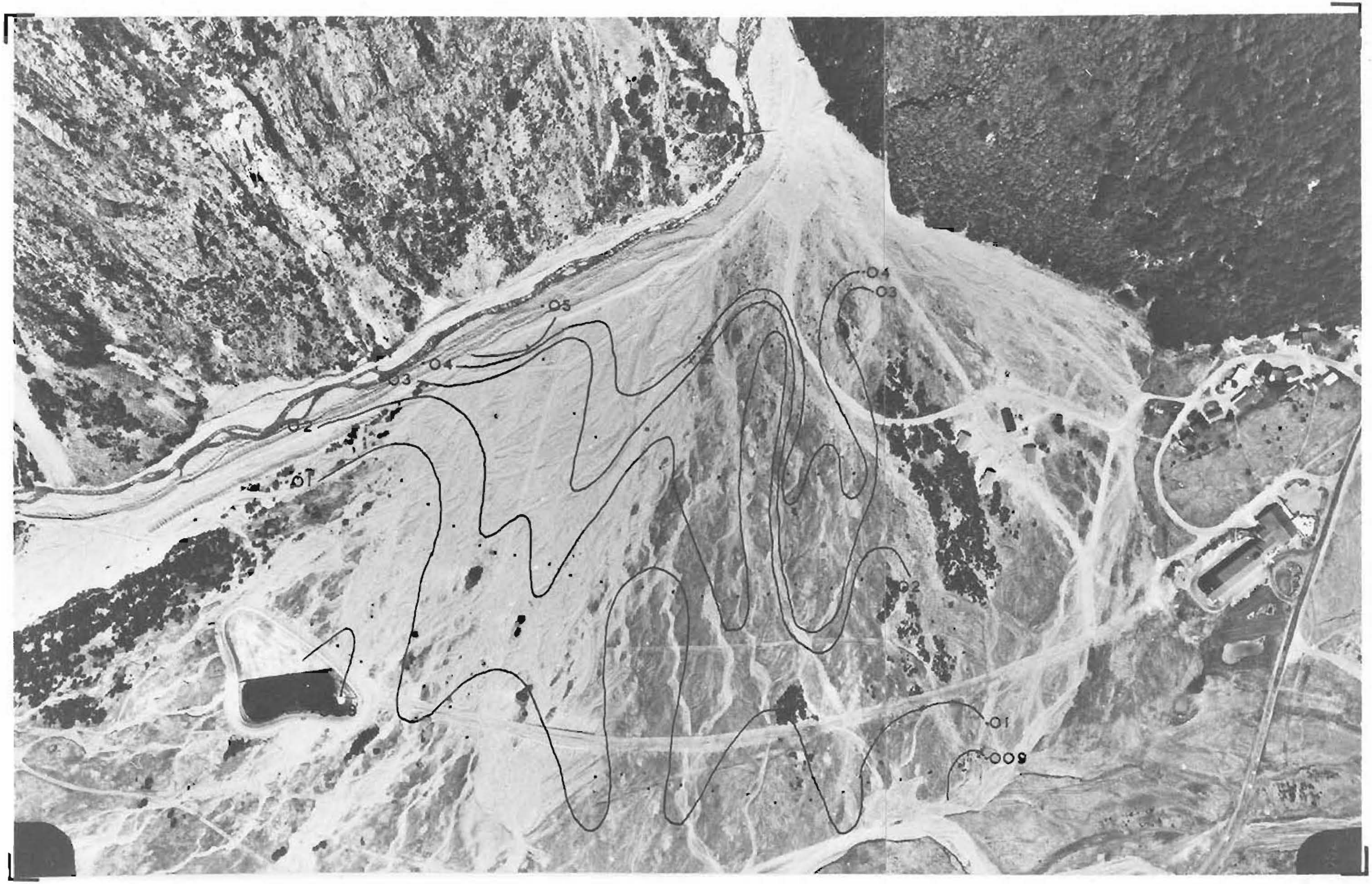

Table 2. Statistical analysis of dS products.

Traverse elevation	Mean dS	Standard deviation	No. of readings	Value of "t" calculated	Significance
710	.016	.0053	19	3.608	At 5%
715	.025	.0084	18	4.717	At 5%
722	.043	.0127	11	0.208	Not sign.
730	.042	.0105	7		

3.5.2 Particle-Size Studies.

The results of the tractive-force studies can be confirmed by contouring the distribution of maximum particle-size on the fan. In this test the longest, intermediate, and shortest axis lengths for each particle are averaged to give a value which is the diameter of the spherical equivalent of the particle. Table 1 column ii) records the lengths of the three axes and the average of these is recorded in column vi). These values are contoured in fig. 16. The mean values of each traverse were calculated and then compared using Student's "t" test. The results are tabulated in table 3. Conclusions similar to those for the tractive-force studies can be drawn from the statistical analysis.

Fig. 16 Contours of equal mean particle-size. 0.1m intervals.

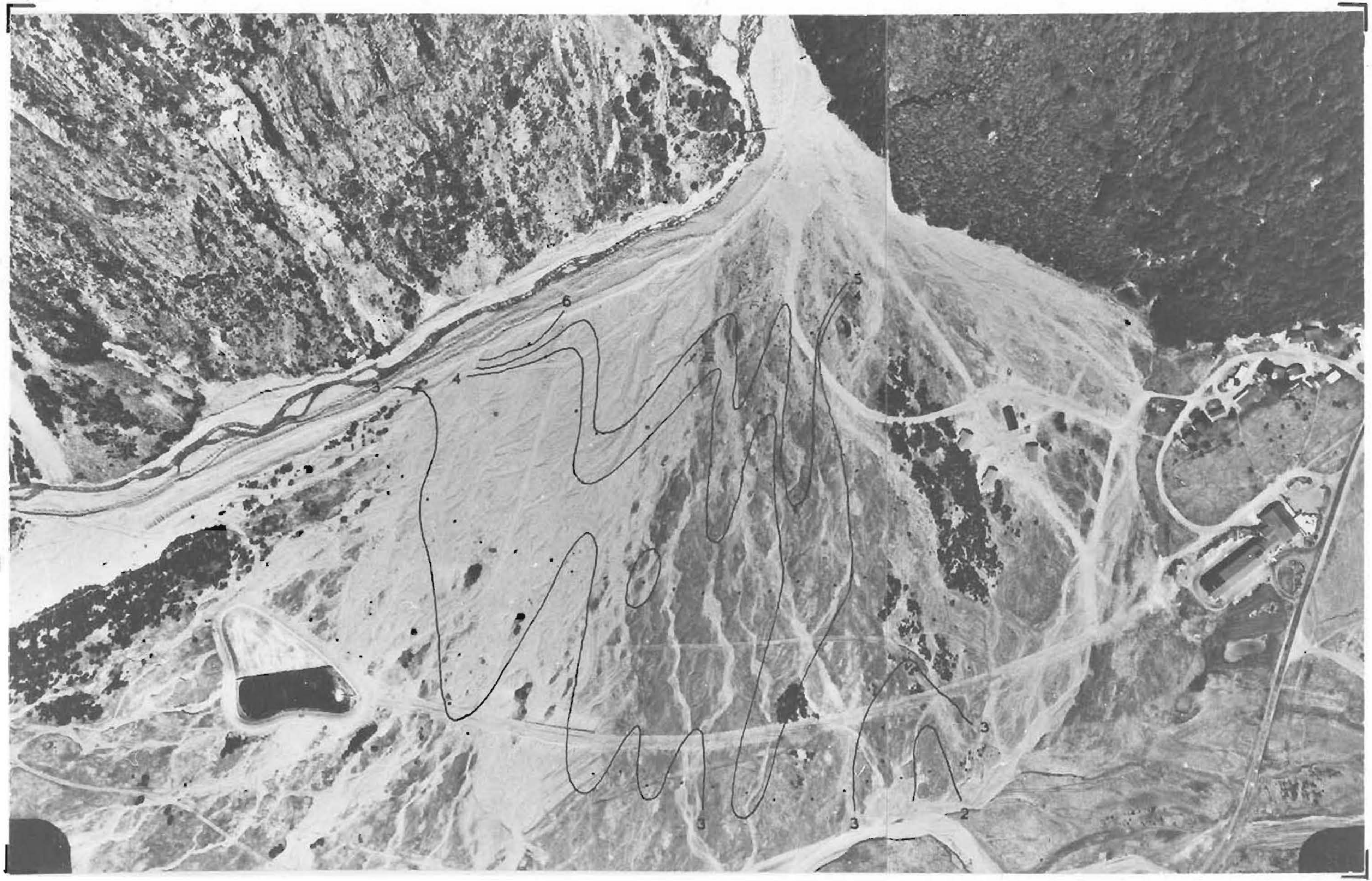
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Table 3. Statistical analysis of mean particle sizes.

Traverse elevation	Mean diam m.	Standard deviation	No. of readings	Value of "t" calculated	Significance
710	.288	.0713	19	2.044	At 5%
715	.335	.0670	18	3.625	At 5%
722	.452	.1070	11	0.019	Not sign.
730	.453	.0814	7		

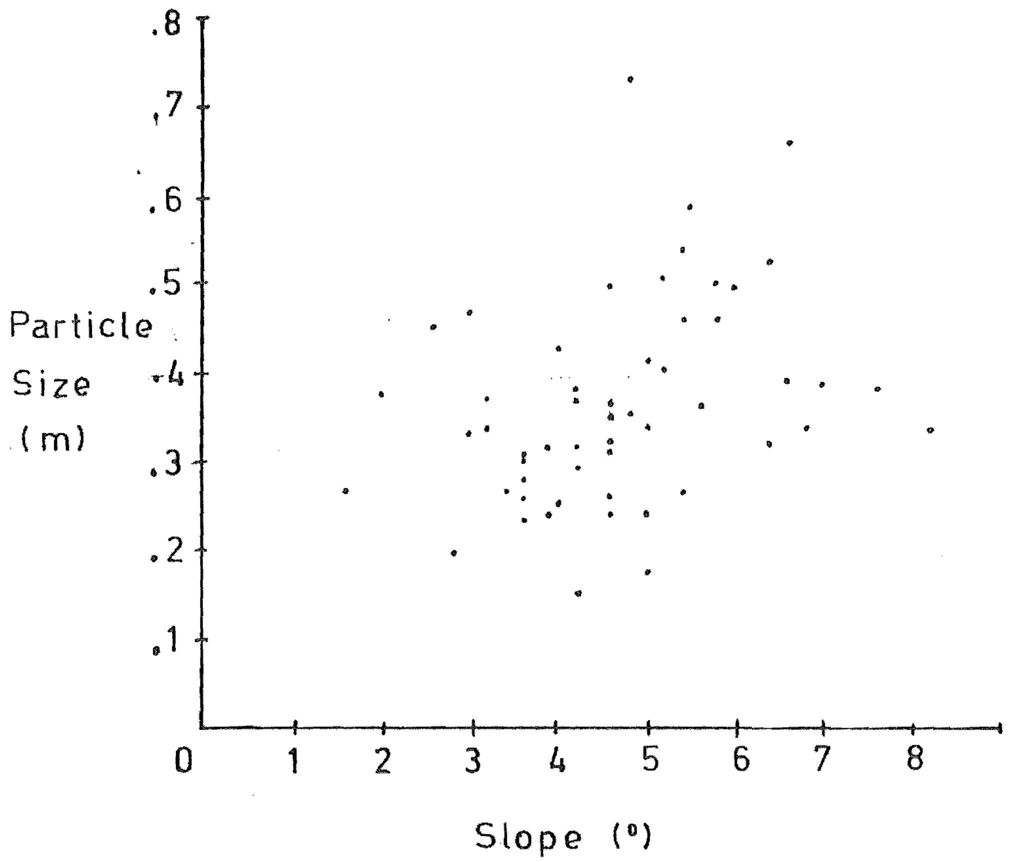
Further proof of the dS relationship is given by graphing the length of the average axis against the slope (fig. 17). Using the product-moment correlation coefficient, a positive correlation significant at the 5% level is found ($r = 0.301$); larger particles are found to be associated with steeper fan slopes.

3.5.3 Granule and Sand Studies.

Because of the size range of the particles on the fan, representative samples of the whole sediment size range would need to be very large. Tests on the smaller size range were therefore confined to the granule and sand-sized fractions.

A) Field and Laboratory Tests. A total of fifteen samples was collected in the field. Fan material was put through a 318mm sieve until a large bucket of sediment was collected; this was then mixed and a 2Kg sample was taken from this for further analysis.

Fig.17 Graph of mean particle size vs. slope for particles on the Black Birch fan.



Care was taken not to lose the very fine fraction. The samples were then room-dried and material larger than -2 ∅ was removed. Material below this size was sieved at 1 ∅ intervals from -2 ∅ to + 3 ∅. The weight passing each sieve was weighed and calculated as a percentage of the total.

B) Results. Table 3 records the station number of the sample and the weight percent of material passing the various sieve sizes. Fig. 18 shows these percentages plotted in graphic form with lines drawn to envelope the maximum and minimum percentages of each size. Within the envelope there is considerable variation, but the variation is not consistent with the relative elevations from which the samples were taken.

Table 4 Weight percent of granule sand samples

	Weight Percent Passing.					
Stn.	-2∅	-1∅	0∅	+1∅	+2∅	+3∅
GS24	19.3	21.4	23.1	17.0	11.6	7.6
GS30	20.7	18.6	17.5	20.9	16.0	6.3
GS45	36.3	23.2	17.2	11.3	7.6	4.5
GS26	23.6	21.1	21.6	17.4	11.0	5.4
GS16	24.4	23.1	23.9	15.7	7.9	5.1
GS61	32.2	20.8	19.2	16.5	8.2	3.2
GS50	34.9	21.6	17.5	14.7	7.8	3.5
GS13	25.8	20.9	22.6	19.6	8.5	2.7
GS42	25.8	16.7	16.3	19.6	15.5	6.1
GS17	17.9	16.8	19.6	21.6	15.2	8.9
GS19	30.0	24.7	23.0	15.5	5.3	1.6
GS37	21.9	16.4	14.7	16.9	18.4	11.7
GS18	15.2	15.3	16.5	22.9	19.5	10.7
GS60	30.8	19.4	13.2	15.2	13.1	8.4
GS15	37.4	20.8	16.7	13.0	7.9	4.2

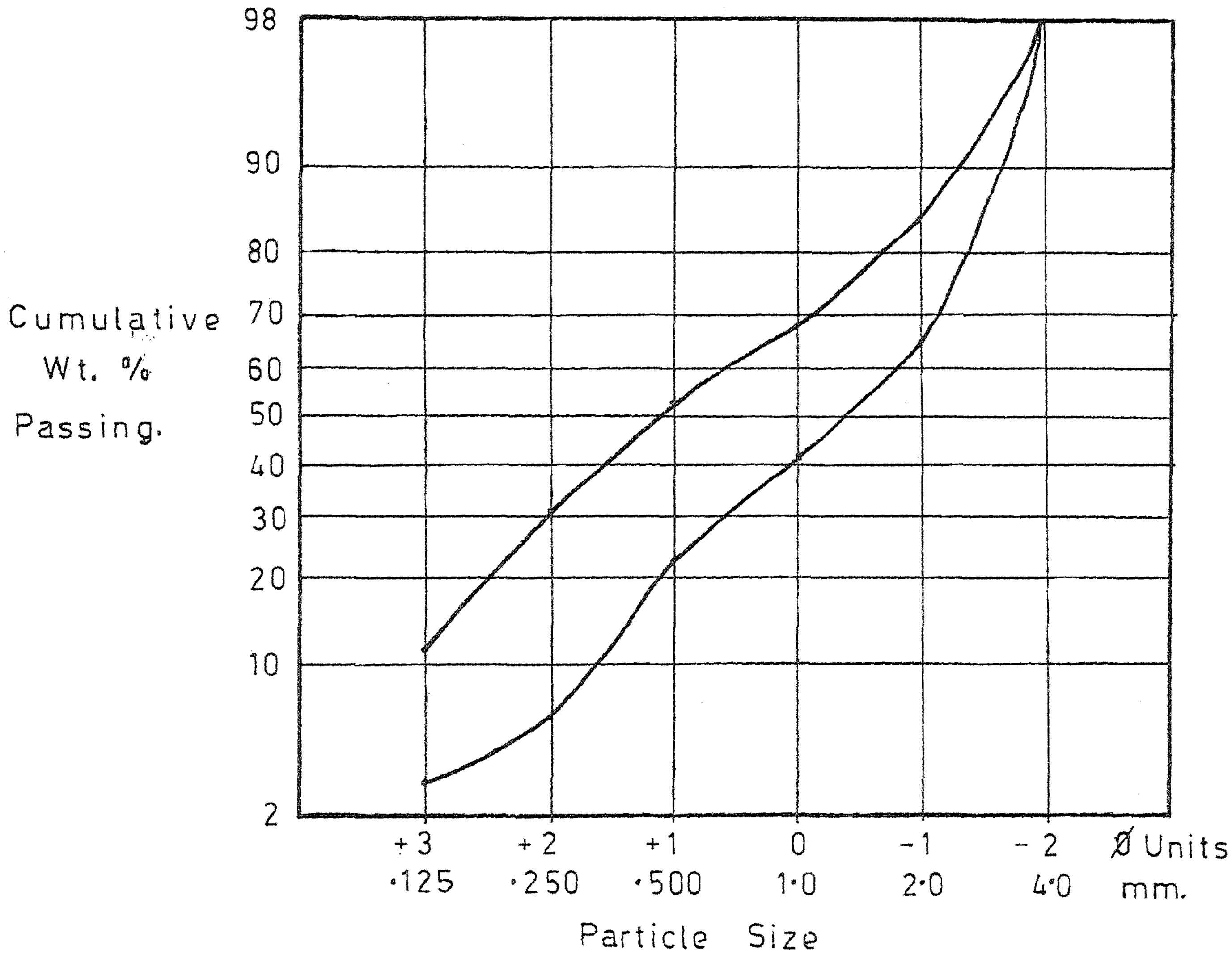


Fig.18 Size distribution of granule to sand sized particles on Black Birch fan. The two curves envelope all the sample variations.

3.5.4 Fan Formation

Theoretical studies of fan formation have yet to provide a simple explanation for the formation of fans. The major problem appears to be that fans are formed in a variety of geological and climatic conditions, and while the outward appearance is similar, the processes forming fans differ from place to place.

In the study area the factors seeming to lead to the formation of a fan are:

i) Frequent stream flooding.

ii) A ready source of supply of sediment. of a variety of sizes.

iii) A highly permeable surface at the outfall of the stream from the valley.

During periods of intense rainfall large quantities of water and sediment are dumped into the main stream channel. The sediment-laden stream flows through the constriction of the gorge where baseflow is added. On reaching the fan, energy is dissipated as the stream descends the fan surface due to water loss and the effects of friction. Particles are deposited on the surface, the larger particles near the fan apex and the smaller particles near the fan base. As the energy of the flow decreases at the conclusion of the flood, finer sediment is deposited in a moving front up the fan slope. This mechanism accounts for the decreasing size of the largest particles down fan and the sand sizes over the whole area. As a result there is a greater range of particle size near the apex compared to the base.

? result of your observation

This mode of formation is further evidenced by the channel deposits found on the fan. A cross section of a channel displays larger particles on the sides and the base of the channel, with deposits of fine particles overlying the larger particles on the base of the channel.

3.6 THE STREAM CHANNEL.

Black Birch stream runs in a narrow channel from the head of the catchment to the fan surface. Within its length many tributary streams join it; most of these are ephemeral. Because of the porous nature of the fan, flow may cease within a few metres of the gorge outlet during dry periods. Recent work by the Ministry of Works has diverted the stream from its natural flow over the fan into a channel along the base of the Mt. Sebastopol buttress. The upper parts of the stream channel serve as avalanche chutes during winter and early spring (fig. 24).

3.6.1 Particle-Size Studies.

A) Methods and Results of Quantitative Study.

Because of the disturbance in the lower reaches of the stream little work of a quantitative nature could be undertaken since it appeared that the stream was adjusting to a new gradient. In May 1975 a profile from the Sebastopol bridge to the first waterfall

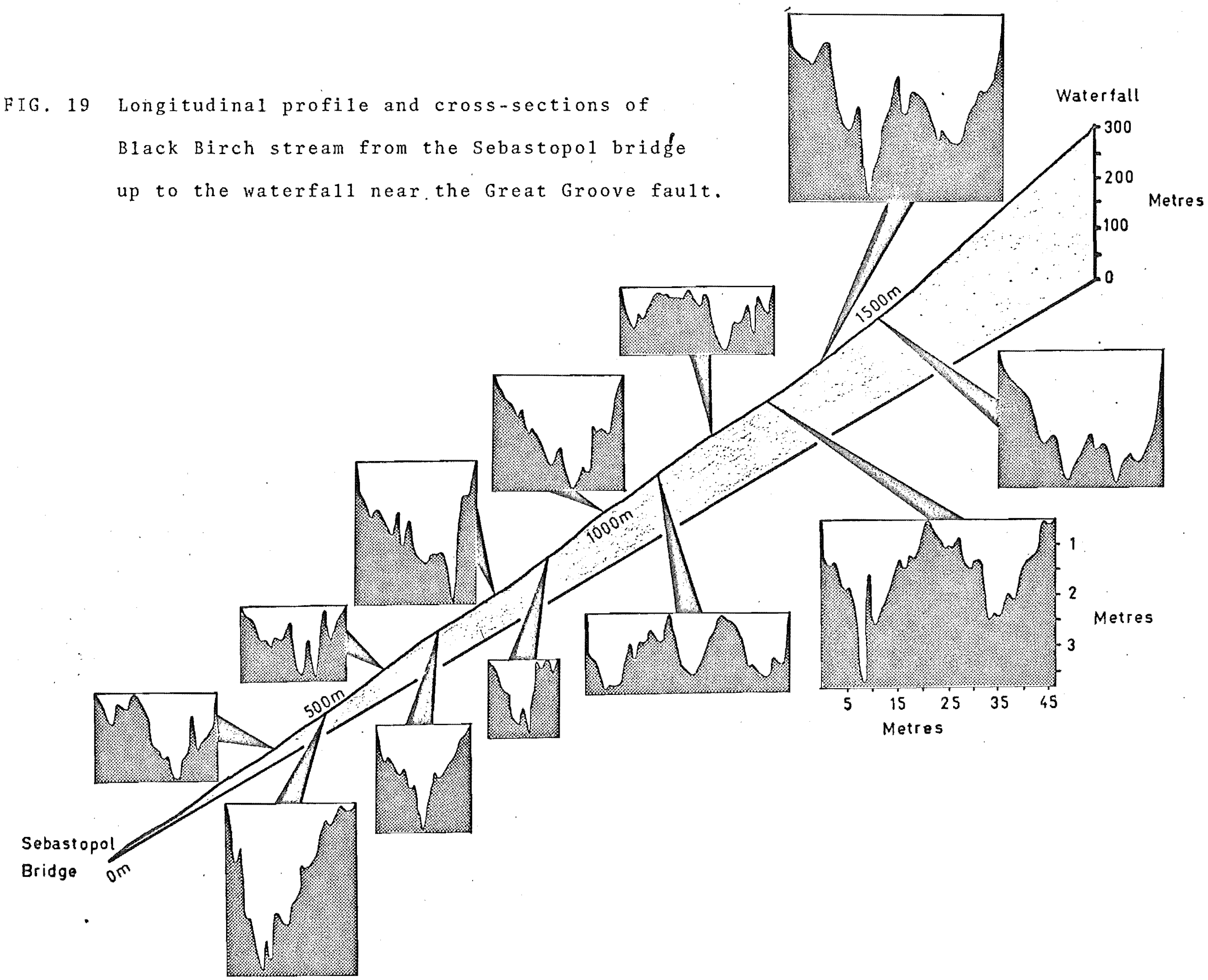
aggrading or degrading

was measured using a tape and altimeter and this is shown in fig. 19. At 100m intervals along the profile cross-sections of the stream channel between the vegetation lines were measured and they also appear in fig. 19. At each cross-section the three axes of particles falling under a line at 1m intervals were measured. The lengths of the intermediate axes are plotted against the distance upstream from the bridge in fig. 20; the mean axis length for particles at each cross-section is calculated and marked. Using the product-moment correlation coefficient a negative correlation was found at the 5% level of significance ($r = -0.710$) between the mean lengths of particle axes and the distance upstream (i. e. the length of the axes increases downstream).

? all pebbles
or larger pieces

B) Analysis. The apparent increase in the size of the particles downsteam could at first be considered a fault of the sampling technique and subsequent statistical analysis. Fig. 19 demonstrates that the stream channel narrows towards the bridge, a result of entrenchment in a rock gorge. This has the effect of reducing the number of measurements of particle-size and consequently widening the dispersion of the sample compared with the cross-sections from further upstream. The results are consistent with general observations in the stream and the nature of the steam processes. To test fully the results, sediment from two areas, one at approximately 500m upstream and one at 1000m

FIG. 19 Longitudinal profile and cross-sections of Black Birch stream from the Sebastopol bridge up to the waterfall near the Great Groove fault.



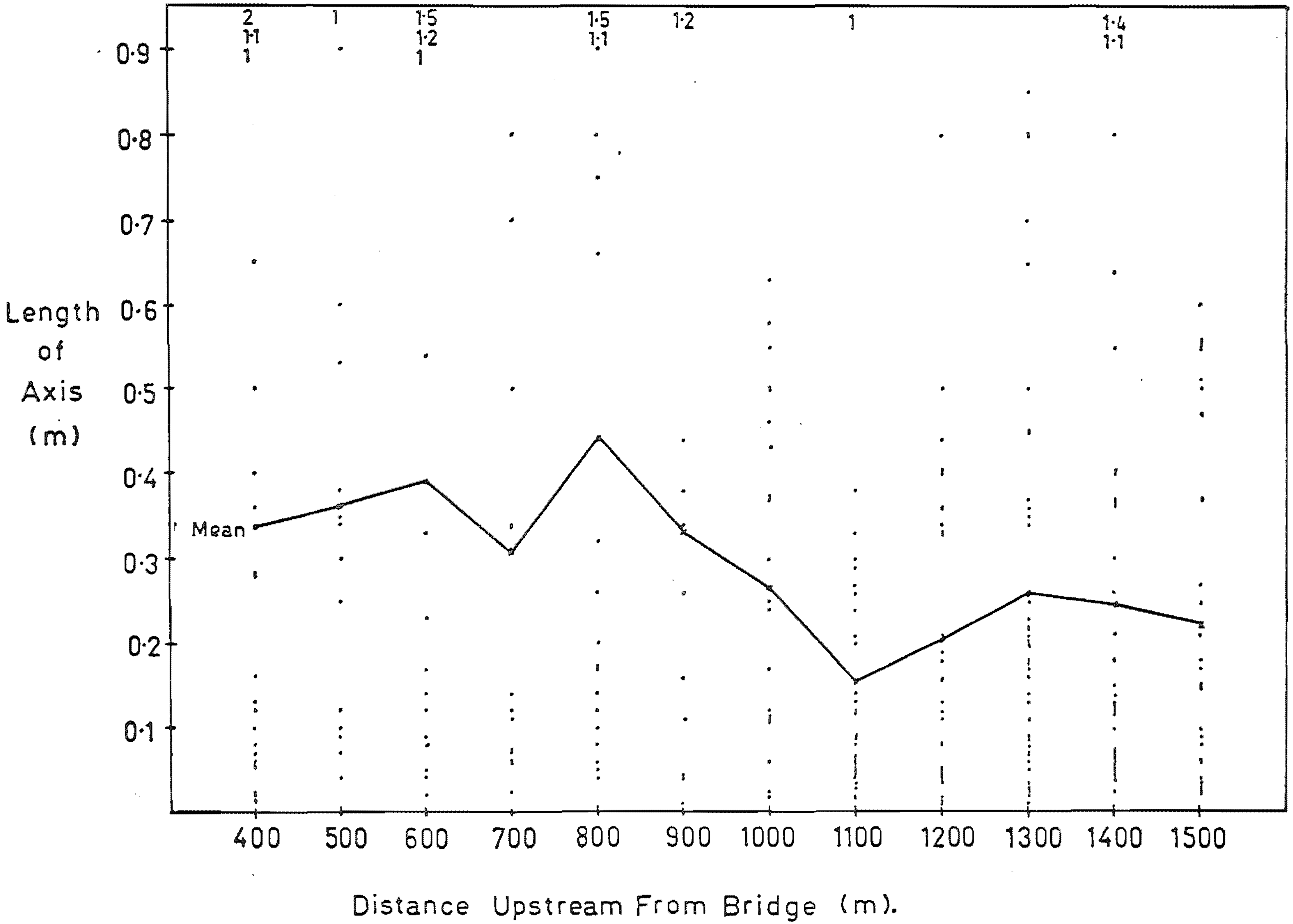


Fig.20 Graph of stream particle size vs. distance upstream from the Sebastopol bridge. The solid line shows the mean particle size for each sampling station.

upstream, were sampled using similar methods to those used by Wolman (1954) and McPherson (1971). Fifty particles were measured at 1m intervals along two 25m traverses 5m apart in each area. At the area 500m upstream the average length of the intermediate axis was 0.289m, and 1000m, 0.173m.

In the region of the gorge only small quantities of sediment are added to the stream channel, mainly because of the lack of glacial deposits in the immediate vicinity and the greater density of vegetation. Tributaries are infrequent. Upstream from the gorge, glacial deposits are adjacent to the channel, vegetation is less dense, tributaries are frequent, structurally the rocks are more disturbed, and avalanche action is more frequent and pronounced. These factors lead to large quantities of material of various shapes and sizes being dumped into the stream in the higher reaches.

Because bedload movement is a sporadic process associated with floods, the finer material in the upper reaches remains in-situ until the stream is competent enough to transport it through the gorge and onto the fan; larger non-transportable material is left in the stream channel during these periodic floods. Since erosion is a continuous process, after a time smaller particles build up in the higher reaches of the channel, their greater abundance being reflected in the mean length of the particle axes.

Protection of the upper reaches from erosion by snow avalanche deposits also a possibility.

This requires a large flood [illegible] followed by a series of [illegible] floods.

4. GEOMORPHOLOGY

4.1 INTRODUCTION.

Most aspects of the descriptive geomorphology are covered in other parts of this study. A map of observed elements of the landscape has been reproduced in map 3. The symbols used are in accordance with suggestions made by the U. K. Geological Society Engineering Group Working Party Report (Anon 1972). Some modifications have been made to suit local conditions.

Two quantitative methods of analysing the catchment area were carried out. The first method is hypsometric analysis. As well as being an index of catchment form, the method can be extended to give a value for the surface-area and average catchment slope. The hypsometric curve has limited applications in later sections on hydrology. The second method, quantitative slope analysis, gave maps that were useful aids in compiling the geomorphological and geological maps; geomorphological features and geological boundaries could often be identified from changes in slope and the areal form of slopes.

4.2 HYPSOMETRIC ANALYSIS.

Hypsometric analysis was first discussed by Strahler (1952) and he defined it as "the study of the distribution of ground-surface area, or horizontal cross-sectional area, of a landmass with respect to elevation".

Working from the topographic base-map (map 1) the catchment area (A) is measured using a polar planimeter. The areas (a) enclosed by each contour and the upper perimeter are also measured. The hypsometric curve is constructed by plotting on a graph the proportion of the total catchment area (a/A) on the X axis, and the proportion of the total catchment height (h/H) on the Y axis. The term h is the elevation of a particular contour above the lowest point in the catchment, and H is the difference in elevation between the lowest and highest points of the catchment. Table 5 columns i)-v) show:

i) The contour elevations in feet a. s. l.

ii) The contour elevations in metres a. s. l.

iii) The areas enclosed between each contour and the upper perimeter of the catchment in hectares (a).

iv) The ratio a/A where A = 479.3ha.

v) The ratio h/H where H = 1467.7m.

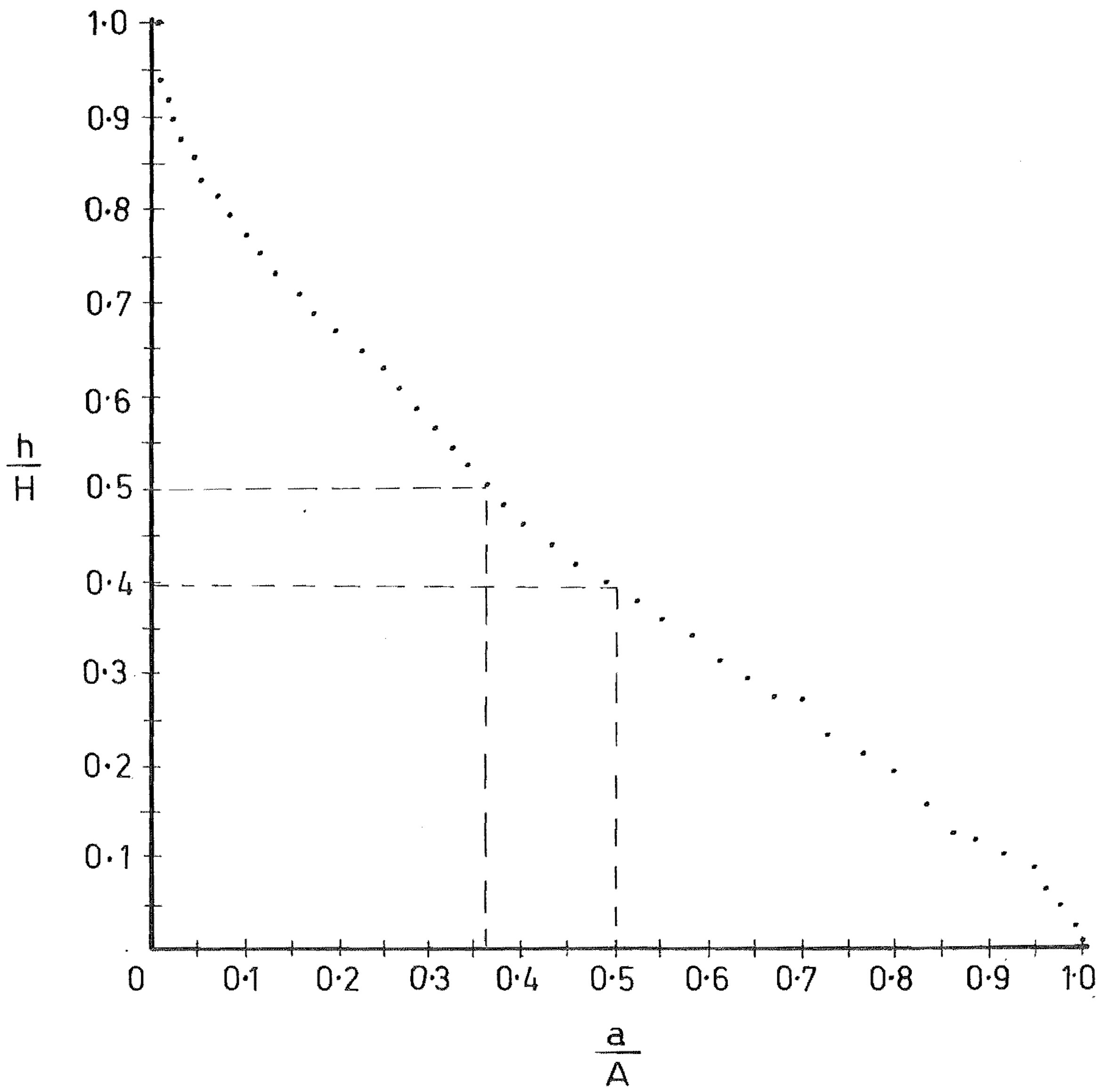
This information is plotted in fig. 21.

The information gained in constructing the hypsometric curve can be further analysed to give the average ground-slope between each contour line. This is carried out by measuring the length of adjacent pairs of contours and averaging these lengths (Lm). The area between the contour belts (At) is calculated from column iii) in table 5. The areas (At) are divided by the average length of adjacent pairs of contours (Lm) to give the mean horizontal width between the adjacent contours

Table 5 Hypsometric data.

i) RL ft	ii) RL m	iii) a ha	iv) a/A	v) h/H	vi) At ha	vii) Lm m	viii) Wh m	ix) S	x) Ag ha
2500	762.5	475.0	.992	.000	-	-	-	-	-
2600	793.0	470.2	.981	.044	4.8	1010.7	49.0	32	5.8
2700	823.5	460.5	.961	.065	9.6	1521.2	63.2	25	10.9
2800	854.0	453.4	.946	.086	7.2	1980.6	36.4	39	9.6
2900	884.5	437.8	.913	.106	15.6	2419.6	64.5	25	17.4
3000	915.0	427.0	.885	.127	13.8	2797.4	49.4	31	16.5
3100	945.5	412.2	.860	.148	11.7	3042.4	38.6	38	15.0
3200	976.0	399.3	.833	.169	12.9	3297.6	39.2	37	16.6
3300	1006.5	382.6	.798	.190	16.7	3491.6	48.0	32	20.0
3400	1037.0	366.8	.765	.210	15.7	3603.9	43.8	34	19.6
3500	1067.5	349.4	.729	.231	17.5	3716.2	47.0	32	21.3
3600	1098.0	333.9	.697	.252	15.5	3838.7	40.5	37	19.4
3700	1128.5	320.9	.669	.273	13.0	3889.8	33.5	42	17.7
3800	1159.0	305.4	.637	.293	15.4	3940.8	39.2	37	19.9
3900	1189.5	291.1	.604	.314	14.3	3991.9	35.8	40	18.9
4000	1220.0	276.2	.576	.335	14.9	3940.8	37.9	38	19.5
4100	1250.5	262.2	.547	.356	13.9	3899.9	35.7	40	18.5
4200	1281.0	249.2	.519	.377	13.3	3940.8	33.8	42	17.9
4300	1311.5	232.5	.485	.397	16.4	3981.4	41.2	36	20.6
4400	1342.0	217.8	.454	.418	14.6	3808.1	38.5	38	18.8
4500	1372.5	204.8	.427	.439	13.0	3409.9	38.2	38	16.8
4600	1403.0	191.3	.399	.460	13.5	3256.8	41.5	36	16.8
4700	1433.5	179.9	.375	.480	11.4	3185.3	36.3	39	15.4
4800	1464.0	170.4	.356	.501	9.5	2907.5	32.8	42	13.2
4900	1494.5	162.5	.339	.522	7.9	2674.8	29.6	45	11.5
5000	1525.0	153.8	.321	.543	8.6	2603.4	33.3	42	11.8
5100	1555.5	144.1	.301	.564	9.8	2613.6	37.5	39	12.6
5200	1586.0	134.9	.282	.584	9.1	2644.2	34.5	41	12.3
5300	1616.5	126.2	.263	.605	8.7	2654.4	32.9	42	12.1
5400	1647.0	117.4	.245	.626	8.8	2634.1	33.5	42	12.0
5500	1677.5	107.1	.224	.647	10.3	2583.0	39.8	37	13.0
5600	1708.0	92.8	.194	.667	14.3	2593.2	55.2	28	16.8
5700	1738.5	81.0	.169	.688	11.8	2603.4	45.3	33	14.5
5800	1789.0	72.2	.151	.709	8.8	2593.2	34.0	41	12.0
5900	1799.5	61.9	.129	.730	10.3	2542.1	40.7	36	13.1
6000	1830.0	53.5	.112	.751	8.4	2583.0	32.5	43	11.5
6100	1860.5	46.7	.097	.771	6.8	2399.3	28.3	47	10.0
6200	1891.0	38.5	.080	.792	8.2	2327.8	35.5	40	11.0
6300	1921.5	31.7	.066	.813	6.7	2307.3	29.1	46	9.7
6400	1952.0	24.1	.050	.834	7.7	2184.8	35.2	40	10.3
6500	1982.5	19.5	.041	.855	4.5	1898.9	23.9	51	7.6
6600	2013.0	13.7	.029	.875	5.8	1521.2	38.3	38	7.5
6700	2043.5	9.9	.021	.896	3.8	1123.0	33.8	42	5.1
6800	2074.0	6.8	.014	.917	3.2	816.8	38.6	38	4.0
6900	2104.5	2.1	.004	.938	4.7	663.7	70.7	23	5.2
7351	2230.0	-	-	1.00	2.1	561.6	37.5	39	2.7

Fig.21 Hypsometric curve for the Black Birch catchment.



(Wh). The ground slope is calculated using the formula:

$$\tan S = C/Wh$$

where S = average ground slope between adjacent contours.

C = contour interval.

Table 5 columns vi)-ix) show:

vi) The area between a specified contour and the lower adjacent contour (At).

vii) The mean length between a specified contour and the lower adjacent contour (Lm).

viii) The mean width between a specified contour and the lower adjacent contour (Wh).

ix) The average ground slope between a specified contour and the lower adjacent contour (S).

This information is displayed in fig. 22 where on the X axis the cumulated mean widths (Wh) are graphed against the Y axis of contour elevations. The average slope between the contours is marked on the curve. The average slope of the catchment was found to be 37.8°.

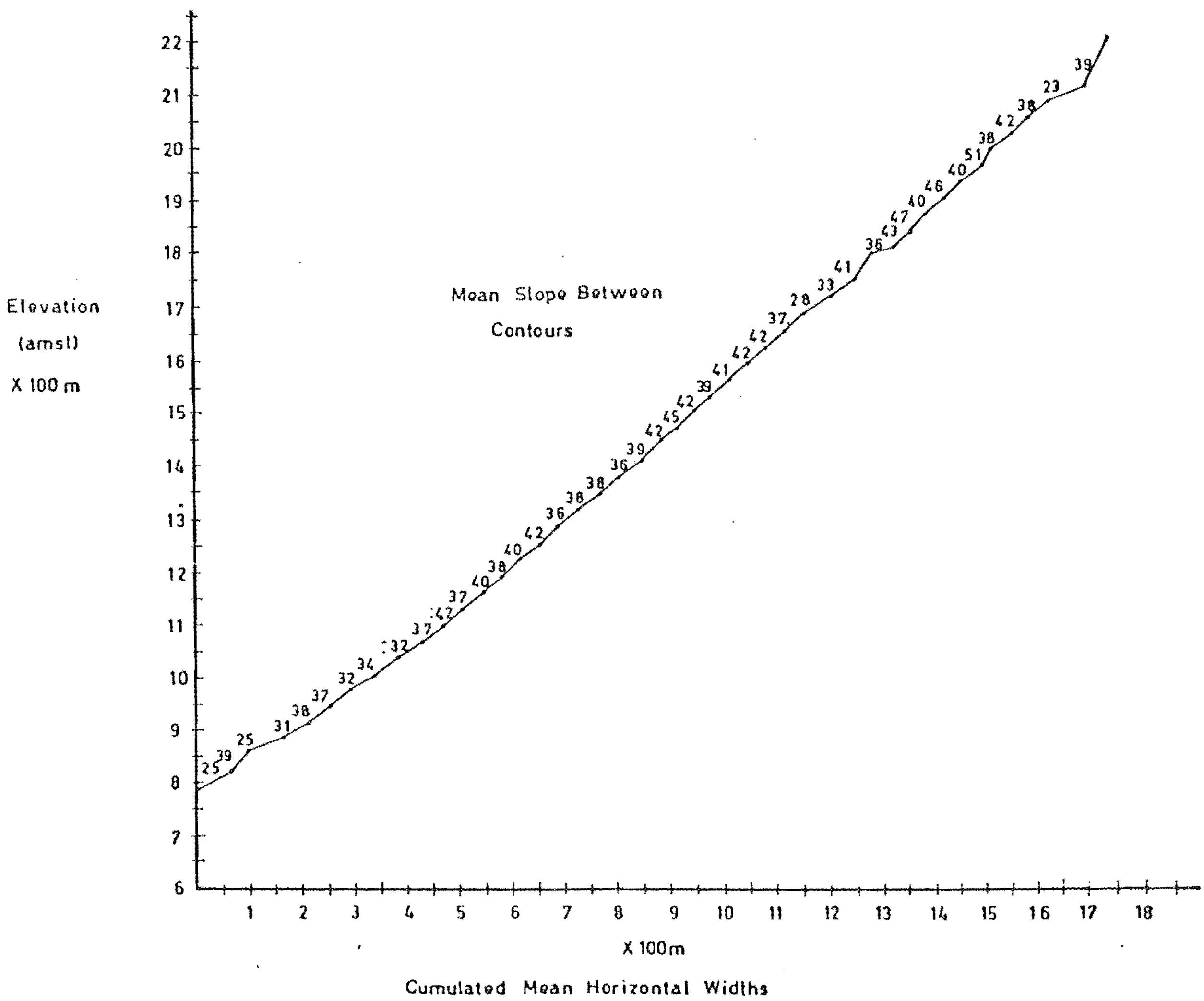
By using the average slope between contours and the mean widths between the contours, the true surface area (Ag) of the catchment can be found by using the formula:

$$Ag = Wg \cdot Lm$$

where Wg = mean width between contours measured on the ground surface.

$$Wg = \frac{C}{\sin S}$$

Fig.22 Mean slope between contours in the Black Birch catchment.



The total surface area was found to be 616.9ha as compared with the map or horizontal area of 479.3ha.

4.3 QUANTITATIVE SLOPE ANALYSIS.

While hypsometric analysis can give a figure for the average slope of the entire catchment, and the vertical distribution of slopes, the areal distribution requires other methods. Strahler (1956) records a method of determining the areal distribution of slope components, and methods of statistical analysis of the areas involved.

Using the topographic base-map (map 1) the catchment is outlined and placed over a grid. At the intersection of the lines of the grid the slope is measured using the formula:

$$\tan \theta = V/H$$

where θ = ground slope.

v = the vertical distance between two points measured along a specified horizontal distance H.

The distance H is usually chosen as the length between intersections on the grid, and in this case was equivalent to 102.1m on the ground. A pair of dividers was set at this distance and at each intersection they were held orthogonally to the direction of the contours and the vertical distance read off. The slope angle was calculated and marked on the map and the values were contoured in 10^{o} increments (see map 4).

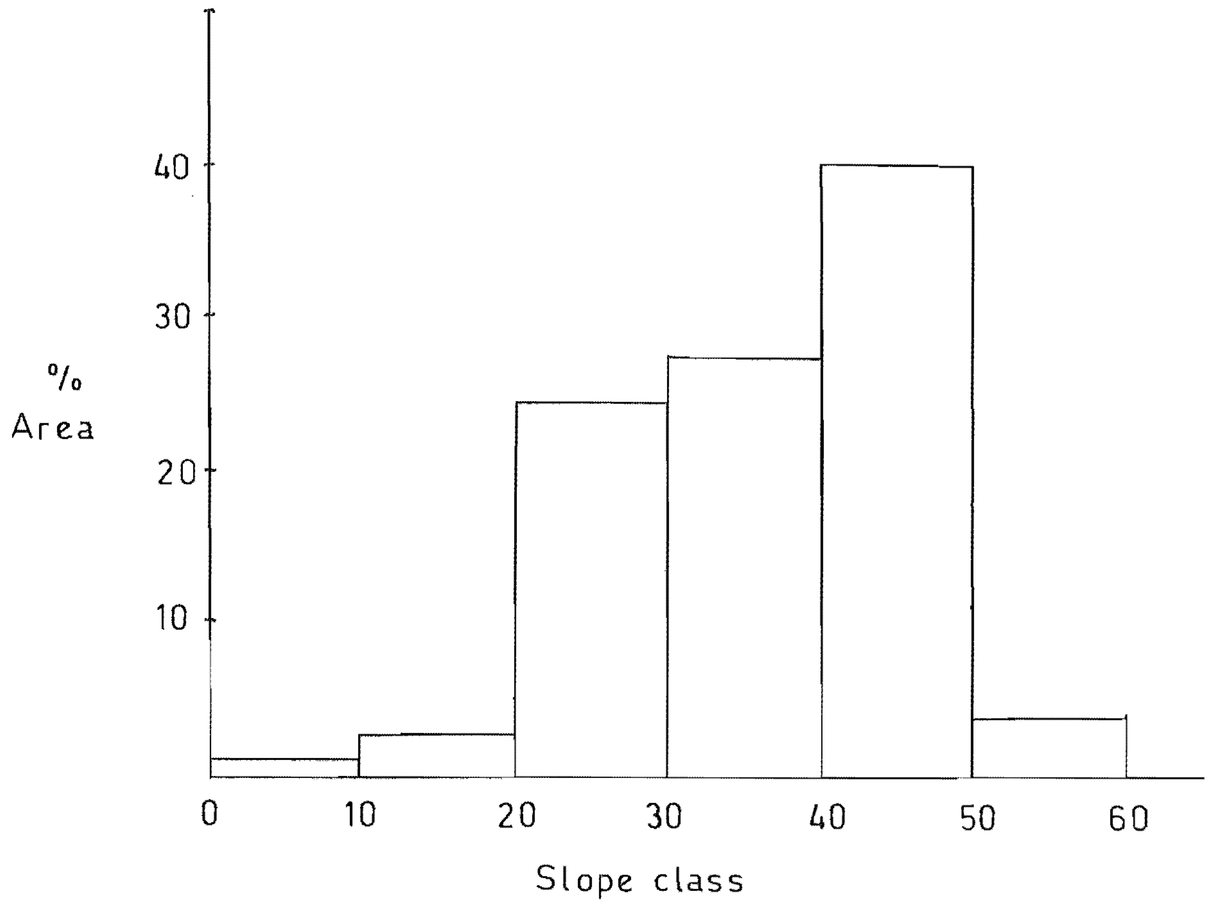
In effect the average slope in a square with 102.1m sides was measured. A slope frequency histogram can be constructed from this information using two methods; by measuring the areas within each contour using a polar planimeter, or by assuming that each slope value is representative of an identical area in each case. The second method was chosen because of its inherent simplicity. The slope histogram is shown in fig. 23. The mean slope of the entire catchment was calculated as 37^o; this figure agrees with the figure derived using hypsometric analysis.

4.4 SLOPE STABILITY.

An indication of the stability of a slope can be gained by studying the presence or absence of landslides on that slope. Slope failures may be triggered off by water saturation causing overloading, by earthquake vibration, or by changes in the long term environmental conditions.

Two slope failures were obvious in the field, both in deposits of colluvium, one below an outcrop of greywacke (fig. 11) and one below the trace of the Great Groove fault (fig. 10). Both are marked on map 3. No other obvious landslides were seen in the field but in the unvegetated areas it is unlikely that they would be seen because frost-shattering and scree development would cover the scars fairly rapidly.

Fig.23 Slope area histogram for slopes in the Black Birch catchment.



Both the observed landslides left shallow scars and the zone of separation between disturbed and undisturbed material was sharp. Using the classification suggested by Varnes (1958) the landslides are called "debris avalanches" and their movements are said to "resemble those of viscous fluids". The characteristic material involved in this type of movement is unconsolidated mixed rocks, soil and clay.

No identifiable landslides were found in the glacial deposits. The main method of slope modification is by gully, frost and probably wind erosion. Fresh slopes, such as those along the sides of tributary streams, are commonly found to be vertical. ([illegible])

Rockfalls are probably common in areas of exposed greywacke and schist but they probably do not involve large quantities of material in any one episode of movement. Large scale rock falls are unlikely since the primary planes of rock weakness, the bedding planes, dip into or are parallel to the slopes.

4.5 AVALANCHES.

Little is known about conditions causing avalanches and the results of avalanche action in New Zealand. Only one paper could be found that mentioned them as a geomorphic process in New Zealand alpine areas (Caine 1969). Because of this, any study of avalanches in the Black Birch catchment can only be compared with work from other countries. Rapp (1960) gives a classification system based on studies in Northern Scandinavia that can be applied to observations in the Black Birch catchment.

An avalanche is so called if more than 50m of movement occur - if less than 50m it is called a snow-slip. If the movement of snow is in contact with the ground the avalanche can be classified as a ground avalanche; if the movement is in contact with snow it is called a slip avalanche. An avalanche can be called clean or dirty depending on the quantity of earth materials within it.

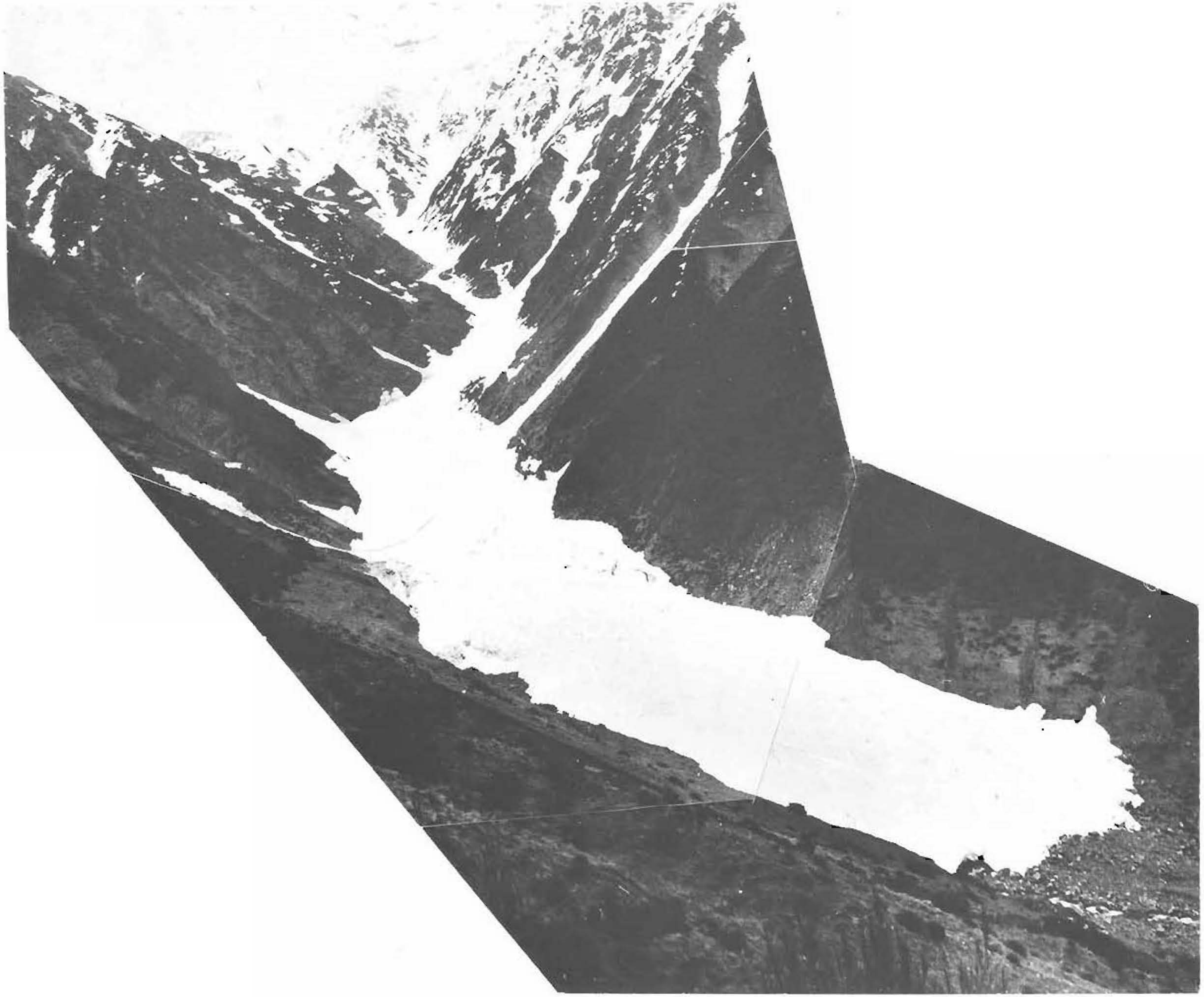
In the Black Birch catchment a large avalanche fills the stream channel from late winter or early spring (fig. 24). Snow depths in the channel are great and the deposits usually remain in the channel over the summer and are often referred to as the Baby glacier. In the summer of 1974-75 the deposits had melted completely by April.

At its origin the avalanche is probably a slip avalanche but as it descends the valley it becomes a ground avalanche. Movement down the channel was observed in October 1975 following a snowfall the preceeding day; the movement was a slow flowing episode.

Other avalanches originate on the steep valley walls, particularly on the north-facing slopes of the catchment. Movement in this case is rapid and the snow tends to powder. The deposits are frequently dirty.

Fig. 24 Avalanche in the Black Birch catchment--October 1975. Trim lines can be seen above the avalanche level. A large cirque below and to the left of Mt. Kitchener is noticeable.

Fig. 25 Avalanche in the Black Birch catchment. Trim lines can be seen above the toe of the avalanche. The avalanche snow is generally clean.



5. ENVIRONMENTAL GEOLOGY.

5.1 GEOLOGICAL RISK CONCEPTS.

The analysis of geological risk to buildings and structures is very complex since it depends not only on what risks are possible or probable, but also on the characteristics of the particular building or structure that is threatened. Geological risk is therefore calculated on the basis of the level of damage to buildings and structures that is deemed to be acceptable or not acceptable in terms of frequency of occurrence of a hazard, the cost of the structure involved, the cost of alternative that may avoid the hazard, and the danger to life and limb.

In this study the cause, process, frequency of occurrence and physical effect of geological risks is of more importance than the ability of the engineering structures to withstand or minimise the danger.

5.2 POSSIBLE GEOLOGICAL RISKS.

In the physical environment a number of processes that could be called geological risks can be identified. Three processes that warrant investigation in almost all areas, and particularly in the Black Birch study area, are the effects of earthquakes, landslides, and floods. Three subsidiary processes or events that may exacerbate the processes already mentioned can also be identified in the study area; namely, avalanches, fires, and high intensity rainfalls.

5.2.1 Avalanches.

Avalanches are a common feature in the Black Birch catchment and normally present no risk to the buildings on the fan. Avalanches of exceptional size could be triggered-off by either heavy rainfalls or earthquakes. Heavy rainfalls are not common during the winter period when there is maximum snowcover. The effect of earthquakes would depend on the quantity of snow in the catchment, the magnitude of the earthquake, and the time of day an earthquake struck. All these factors are unpredictable.

There would appear to be little chance of an avalanche damming the flow of the stream and causing flash floods by the rapid release of large quantities of water; the uncompacted avalanche deposits are unlikely to restrict water flow along the channel. It is also unlikely that there would be enough snow or enough of a slope to allow an avalanche to move down the stream and on to the fan surface; this has not been known to happen in the past. If the trim-lines along the channel walls are any indication, this year's avalanche was almost of maximum size and its terminal was about 1 Km upstream from the fan apex.

5.2.2 Fires.

Fires are not geological risks but they can cause them, since a relatively delicate balance between ground cover and hydrological and erosive processes exists in the catchment. Because the Black Birch catchment is within a National Park, public access cannot be restricted even in periods when the fire risk is high (during dry periods in summer and autumn). Should a fire become established it would be hard to control because of the topography and access. Removal of vegetation by fire can cause a decrease in the infiltration rate due to raindrop impact compacting the upper layer of the soil. Increased quantities of water could move overland causing gullying, especially of the glacial deposits, and as a consequence, increase sediment input into the stream. Flood peaks in the stream would be achieved more rapidly, and would be higher, because the time of concentration of the catchment would be reduced and the storage effects of the soil and vegetation would decrease. If the flows and sediment content are greater than the capacity of the lower parts of the stream channel, flooding could occur on the fan.

Landslide activity could be expected to follow the removal of vegetation, especially in colluvium areas. Vegetated screes could also be expected to re-mobilise.

Discussion of [illegible] events would have helped

5.2.3 Landslides.

Prolonged water saturation and short term forces from earthquake shocks are probably the main causes of slope failure in the Black Birch catchment. Water saturation is most effective in producing instability in unconsolidated materials, while earthquake shocks probably have an equal effect on both consolidated and unconsolidated material.

Landslides can also be caused on oversteepened slopes due to undercutting by the stream in both the main channel and the tributary valleys. This process is quite common during flood flows but in general it is a small scale process.

Two possible effects of landslides can be predicted: first, the introduction of large quantities of sediment in to the stream channel causing rapid aggradation of the channel, or second, the damming of the stream followed by overtopping and flash flooding.

From indications of existing forms of landslides, rockfalls are a continuous and relatively small-scale process, while debris avalanches in colluvium are infrequent and not likely to dam the stream or cause rapid aggradation of the stream channel. No landslides were found in the glacial deposits.

5.2.4 Earthquakes.

Earthquake events may directly damage the buildings and associated services on the fan, the extent of the damage depending on the behaviour of the ground and the quality of the structures. They may also trigger off movements in the catchment that could become geological hazards.

In general, gravels of the type found on the ? fan tend to dampen earthquake shocks, but this depends on the proximity of bedrock to the surface and the degree of consolidation of the fan gravels. Lenses of water-saturated sands within the fan might liquify causing subsidence, but no evidence of extensive sand lenses was found. Unconsolidated embankments might also collapse but there are few of these and they are not likely to damage any buildings. In severe earthquakes damage to underground pipes and cables could ? be expected.

The catchment is probably more susceptible to damage from earthquakes. The possible effects on avalanche and landslide activity have already been mentioned.

5.2.5 High intensity rainfalls.

The definition of a high intensity rainfall and the meteorological conditions causing them have already been discussed, as has their role in causing avalanches and landslides. The major geological risk caused by high intensity rainfalls is flooding.

5.2.6 Floods.

Floods can be the result of a variety of processes and most of these have been mentioned in preceding sections.

Before floods of any origin can become a risk to buildings and services on the fan they have to flow close to the buildings and services, and this presupposes that they are large enough to change course from the present channel. To change course involves the breaching or overtopping of earthworks and control structures that at present determine the direction of flow.

What about choking stream with debris

If the occasion does arise when the flow breaches or overtops the present channel then the stream will cause local scouring and widespread deposition of sediment. Any buildings or services that obstruct the flow will be affected by deposition on the upstream side and scour on the downstream side plus damage by rolling boulders in the flow.

The direction the flow may follow over the fan is hard to predict, but initially it would be logical to assume flow over areas with the steepest slope and the smoothest surface.

5.2.7 Conclusion.

Two possible risks can be discarded because there is no evidence that they were ever significant events, and as a consequence, there is no reason to assume that they may become significant. The two possible risks are from avalanches and landslides. (As direct risks)

To attempt to predict the frequency of occurrence of fires in the catchment is impractical because whether fires will occur or not will depend on the responsibility of the people using the area and the management practices adopted by the Park Board.

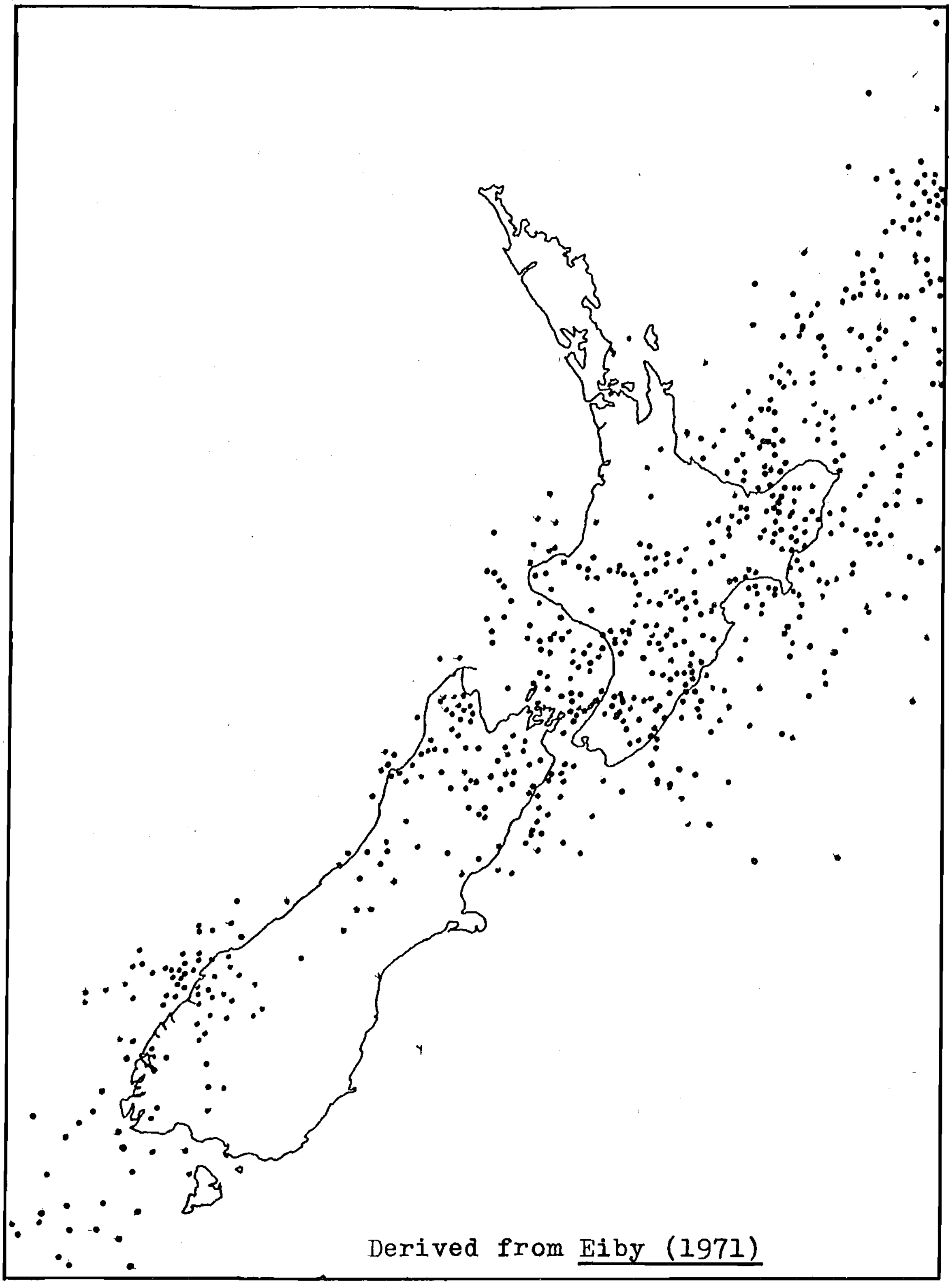
The probability of earthquakes occurring is discussed in the next section of this study. Irrespective of the method of predicting the frequency of occurrence of earthquakes it is doubtful if the magnitude of the event could ever be predicted.

There is geological evidence that in the past floods have been active forces in the environment, and from the short period of recorded history there appears to be a connection between flood events and high intensity rainfalls. The frequency and magnitude of these flood events requires study and discussion so that the risk imposed on buildings and services on the fan can be calculated.

5.3 EARTHQUAKE ACTIVITY.

In spite of the Mt. Cook area being an alpine area and therefore an area that must have undergone a great amount of uplift, there is little evidence that earthquake activity ~~activity~~ is common at present. Fig. 26 presents data of the position of earthquake epicentres for the period 1955-1965 and is derived from Eiby (1971). However records of earthquake actiin New Zealand as a whole cover a period of less than

Fig.26 Distribution of shallow earthquakes in New Zealand of magnitude 4 or greater for the period 1955-65.



50 years and as a consequence, use must be made of geological evidence in preference to statistical studies of recorded earthquakes.

Within the Black Birch study area there are signs indicative of tectonic movement and therefore probable earthquake activity since the retreat of the major valley glaciers. Offset ridges occur on the boundary of the catchment and the stream channel is offset in the vicinity of the Great Groove fault. Appearances may be deceptive, however, since the Great Groove also marks a change in lithology and to some extent structure, and the offsets could be the result of differential erosion. A number of slips occur along the fault zone which may be due to movements or to instability caused by the saturation and crushed nature of the materials in the fault zone.

Perhaps the most acceptable way of describing earthquake activity in the area is to put it in a New Zealand-wide context. A measure of the historic earthquake activity in New Zealand is the amount of deformation found in early Quaternary and Pliocene beds. If areas of differing amounts of deformation are equated to the underlying structure and known geological history then zones of assumed levels of earthquake activity can be drawn over New Zealand. Work of this nature has been carried out by Clark et. al (1965), and the zones derived have been assigned values of seismic risk; that is "the risk of serious damage from earthquakes within a defined period of time". The zones and estimated risks are shown in fig. 27. Clark et.al (1965) qualify this zonation by stressing that ground conditions play a major role in the destructiveness of an earthquake and that "for example the risk on poor ground in zone 3 is greater than the risk on good ground in zone 2". The reaction of the various ground conditions to earthquakes in the Black Birch study area has already been discussed.

A conclusion that could be drawn from the high risk zonation of the Mt. Cook area and the lack of recorded evidence is that the area may be overdue for an earthquake or series of earthquakes. This conclusion depends on the relative accuracy of the two methods of assessing earthquake activity. A greater understanding of seismic activity in the Mt. Cook area may follow studies at present being carried out by the D. S. I. R. of seismic activity related to the raising of Lake Pukaki.

5.4 FLOOD RISK

5.4.1 Introduction.

Wrong. see Hydrology Annual 1957/59

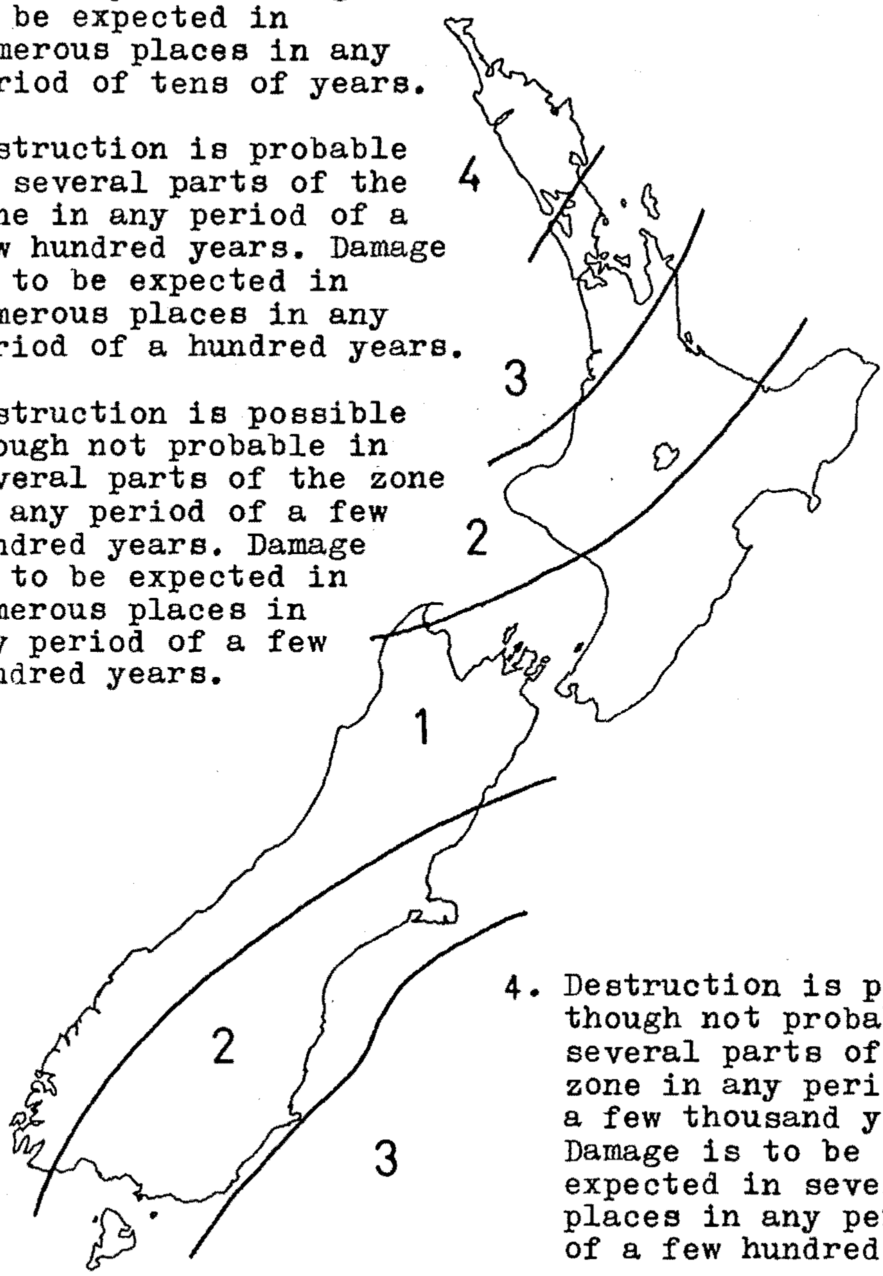
Since no hydrological records exist for the Black Birch stream, the frequency and magnitude of floods must be calculated using indirect methods. Because of the general lack of streamflow records in New Zealand most indirect methods are based on overseas methods with adjustments made for New Zealand conditions.

Fig.27 New Zealand earthquake risk zones.

1. Destruction is probable in several parts of the zone in any period of a hundred years. Damage is to be expected in numerous places in any period of tens of years.

2. Destruction is probable in several parts of the zone in any period of a few hundred years. Damage is to be expected in numerous places in any period of a hundred years.

3. Destruction is possible though not probable in several parts of the zone in any period of a few hundred years. Damage is to be expected in numerous places in any period of a few hundred years.



4. Destruction is possible though not probable in several parts of the zone in any period of a few thousand years. Damage is to be expected in several places in any period of a few hundred years.

Adapted from Clark et.al (1965)

One of the more common indirect methods is the use of empirical formulae where rainfall, catchment, and areal characteristics are quantified and used to predict the peak discharge associated with any particular rainfall event.

The choice of the empirical formula to be used in any particular case is difficult especially if no studies have been carried out in areas of similar topography, catchment characteristics, and climatic conditions so that results can be compared. The Black Birch study area is such a case and the only alternative is to use a method that is widely known and used and note the limitations of the method when applied to the area. The only empirical formula in widespread use in New Zealand was developed by the Soil Conservation and Rivers Control Council, and is issued as Technical Memorandum No. 61 by the Ministry of Works. It is commonly called the TM61 Procedure and was first issued in 1953 and revised in 1959, 1961, and 1964. It is believed that a further revision is being carried out at present.

[illegible] Hooker, Bait Hill & Tollie

5.4.2 The TM61 Procedure

A) The Formula. The formula for the procedure is:

$$Qp = CRSA^{3/4}$$

where Qp = peak discharge.

C = a constant dependent on catchment characteristics (discharge coefficient).

R = rainfall factor.

S = catchment shape factor.

A = catchment area.

Imperial units of measurement are usually used but for this study conversion to metric units must be made.

i) Discharge coefficient C. Two steps are used to determine C. The catchment slope characteristic (Ws) and the catchment infiltration and vegetation characteristic (Wic) are determined separately to give W, the catchment flood-producing characteristic which determines C. Ws is determined from fig. 28 by plotting the channel length against the average channel slope; methods of calculation are detailed in the Memorandum. Wic is determined from table 6; reference to sections on soils, vegetation and the hypsometric curve make the choice of Wic more accurate. The product of Ws and Wic gives a value for W, and C can be derived from fig. 29.

ii) Rainfall factor R. The rainfall factor is the ratio of the depth of a design rainfall of stated return period and duration to a known standard rainfall of the same return period and duration. The standard rainfall depth is a curve proportional to the depth-duration-return

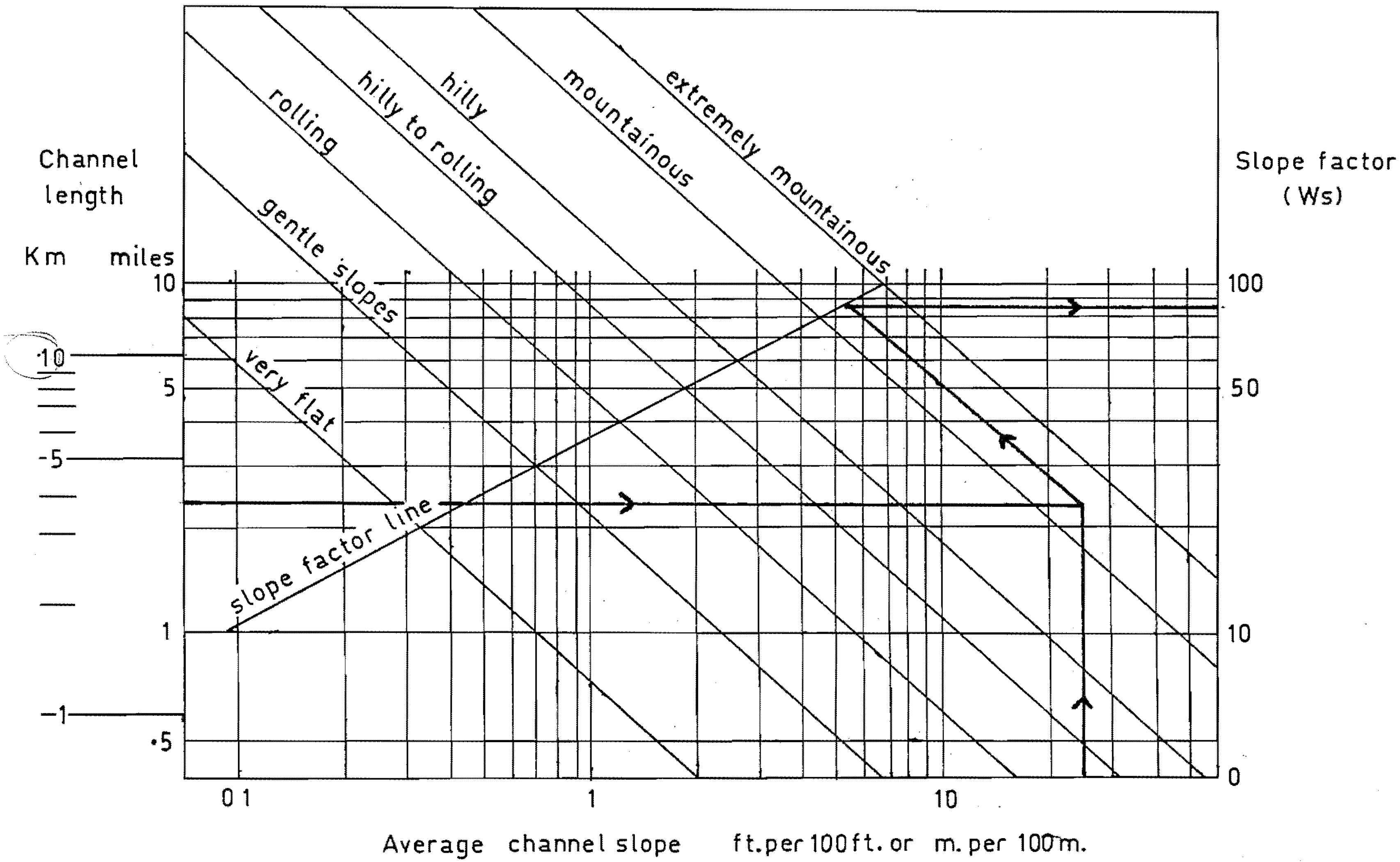


Fig. 28 Slope factor estimation chart for TM61 procedure.

Table 6 Values for catchment infiltration and ground-surface cover characteristic (Wic) for the TM61 procedure.

Soils.	Ground Surface Cover.		Wic
Impervious soils (such as clay soils with poor structure e.g. northern yellow brown earths). Any soil if saturated is included in this group	Urban catchments	High density development	1.8
		Moderate to low density development	1.5
	Mainly bare surfaces		1.2
	Average shortgrazed catchments		1.1
	30% of area in long grass, scrub or bush		1.0
	60% of area in long grass, scrub or bush		0.9
	100% of area in long grass, scrub or bush		0.8
Moderately absorbent soils (such as medium textured soils with good structure e.g. southern yellow brown earths).	Urban Catchments	High density development	1.7
		Moderate to low density development	1.3
	Mainly bare surfaces		1.1
	Average shortgrazed catchments		1.0
	30% of area in long grass, scrub or bush		0.9 *
	60% of area in long grass, scrub or bush		0.8
	100% of area in long grass, scrub or bush		0.7
Absorbent soil (such as deep yellow brown sands and pumice soils).	Urban catchments	High density development	1.5
		Moderate to low density development	1.2
	Mainly bare surfaces		1.0
	Average shortgrazed catchments		0.9
	30% of area in long grass, scrub or bush		0.8
	60% of area in long grass, scrub or bush		0.7
	100% of area in long grass, scrub or bush		0.6

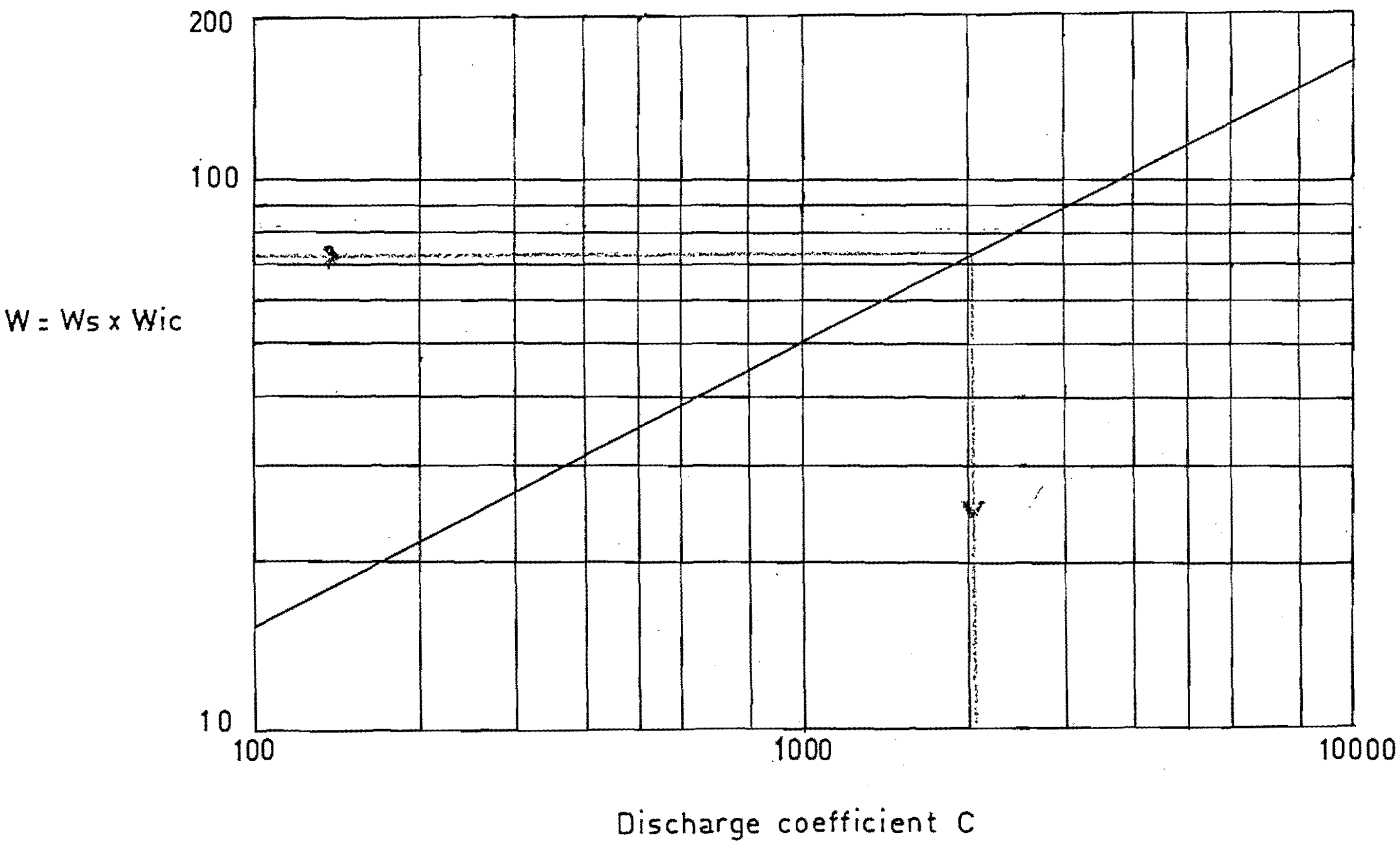


Fig.29 Conversion chart W-C for TM61 procedure.

period relationship existing at Kelburn (Wellington N. Z.) but which has been adjusted to have a rainfall intensity of 76.2mm/hr.

The design rainfall can be calculated using methods and maps given in Robertson (1963). Inherent in the TM61 procedure are the assumptions that the rate of rainfall is the same in all parts of the catchment and that the intensity decreases with duration (that a one-hour storm is more intense than a six-hour storm). The maximum flood will therefore occur at the instant the whole catchment contributes to the flow, that is at the time of concentration, and will be associated with rainfall intensities of equivalent duration to the time of concentration. Before the time of concentration the whole catchment does not contribute to the flow and after the time of concentration the rainfall intensity decreases. The time of concentration is a measure of the time between flood peak and the commencement of overland flow and/or prompt subsurface flow, and this occurs when the rainfall intensity is greater than the capacity of the catchment to absorb and store water.

The time of concentration can be calculated by a variety of methods including studies of lag time between the peaks of a hydrograph and a hyteograph, hydraulic studies using stream channel velocities, and empirical methods. A rough approximation only is required for this study, thus an empirical method is suitable: the formula used is the Bransby-Williams formula (see University of Canterbury 1973):

$$Tc = \frac{0.88L}{A^{0.1}S^{0.2}}$$

where Tc = time of concentration in hours.

L = length along stream channel in miles (1Km = 0.621 miles).

A = area of catchment in square miles ($1Km^2$ = 0.386 sq. miles).

S_T = average slope of catchment (percent).

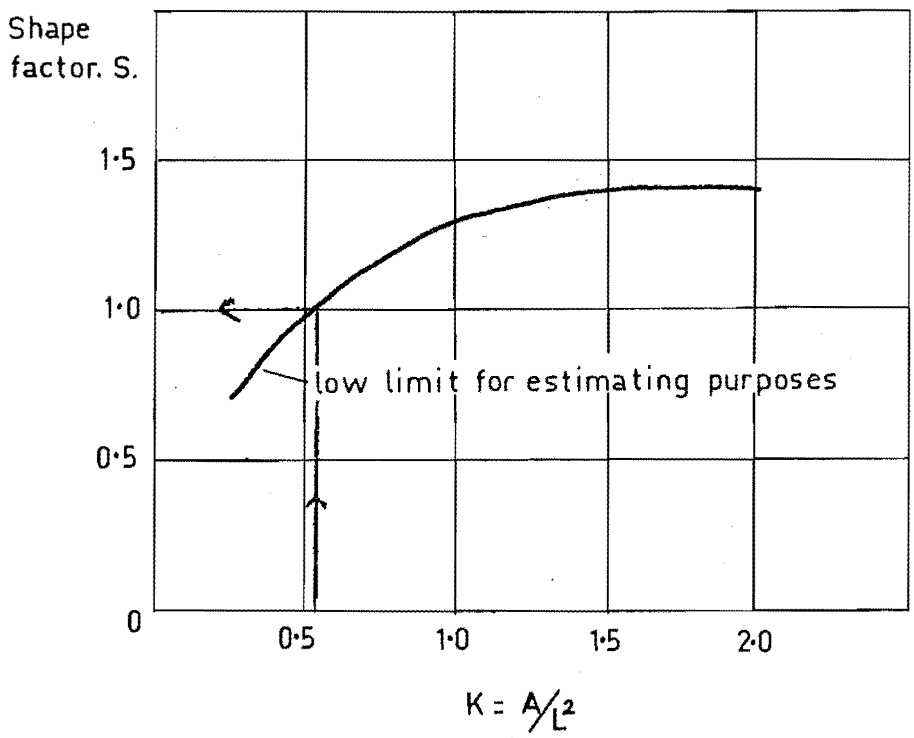
iii) Shape factor S. Fig. 30 allows the shape factor to be read off. The value for K is given by the formula:

$$K = A/L^2$$

Where A = area in square miles ($1km^2$ = 0.386 sq. miles).

L = direct length to the farthest point of the catch-

Fig.30 Shape factor estimation chart for TM61 procedure.



ment in miles (1km = 0.621 miles).

iv) Area A. The area of the catchment is measured ($1km^2$ = o.386 sq. miles).

v) Peak discharge Qp. From the above factors the peak discharge is calculated and converted to appropriate units (1cumec = 35.28 cusecs).

B) Worked Example. Using data from the Black Birch study area the TM61 procedure was applied.

i) Discharge coefficient C. Using the method proposed by Taylor and Schwartz (1952) the average channel slope was equal to 25.8m per 100m. The channel length was 3.6km. From fig. 28.

$$Ws = 85$$

From the section on vegetation and soils, the area above 1365m elevation is almost all bare surface. From the section on hypsometric analysis the difference in elevation between the highest and lowest points in the catchment is 1468m, and the 1365m elevation is 602m above the lowest point, thus

$$h/H = 0.41$$

then $a/A \quad 0.5$

Therefore approximately 50% of the area is bare surface and the remainder is covered with southern-yellow-brown soils with long grass, scrub, or bush. From table 6.

$$Wic = 0.85$$

Therefore

$$W = Ws \times Wic$$
$$= 85 \times 0.85$$
$$= 72.3$$

From fig. 29 the discharge coefficient.

$$C = 2100$$

ii) Rainfall factor R. Fig. 31 shows a graph of rainfall depth against duration for a variety of return periods, and the standard depth-duration curve for the TM61 procedure. The time of concentration was derived from the Bransby-Williams formula:

$$Tc = \frac{0.88L}{A^{0.1}S^{0.2}}$$

where $L = 1.86$

$A = 1.83$

$S = 25.8\%$

thus $Tc = 0.8$ hours (48 minutes).

The rainfall factors at the time of concentration for the return periods are shown in table 7.

Fig.31 Rainfall depth duration curves for Black Birch catchment and TM61 standard curve.

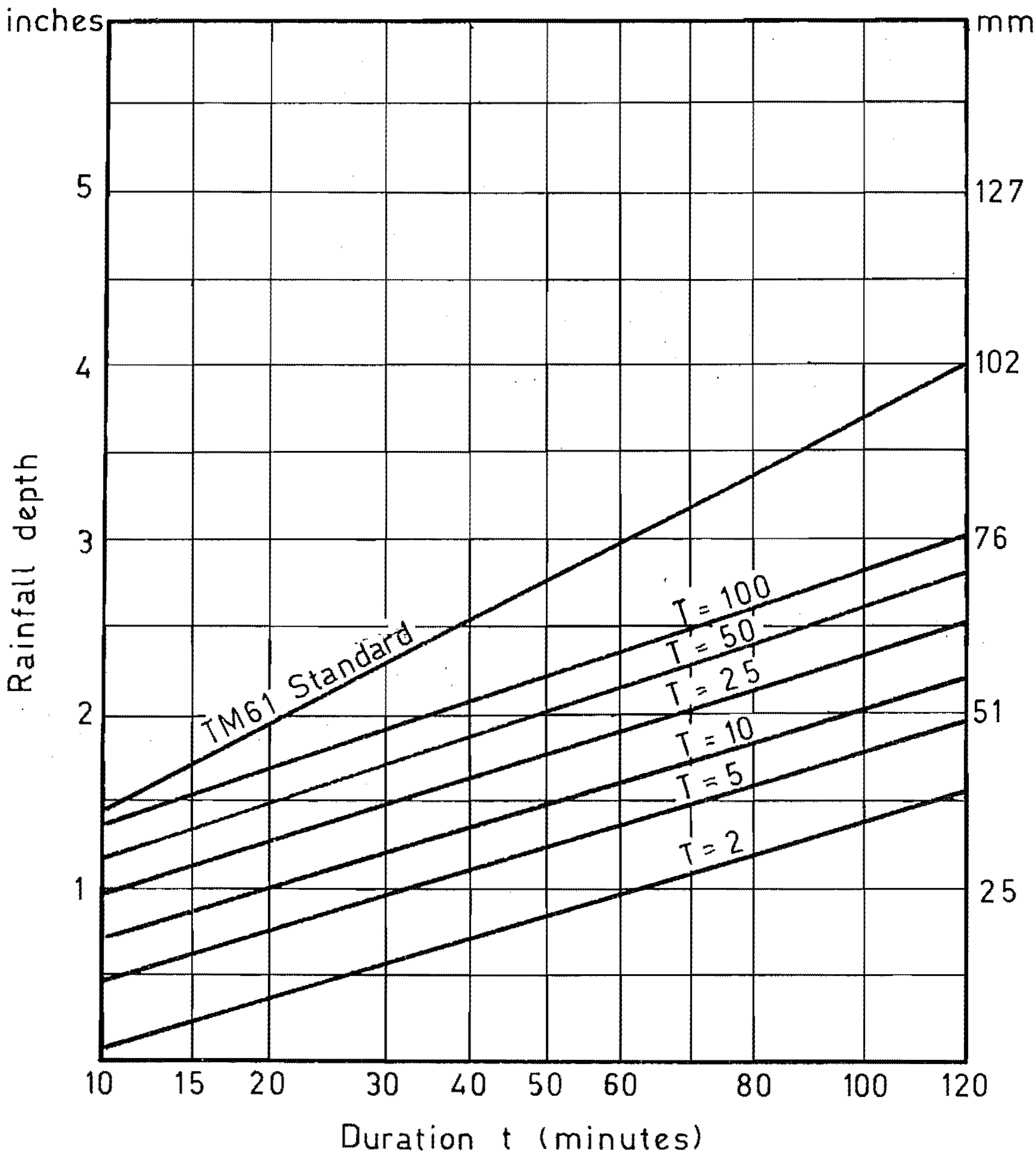


Table 7. Rainfall factors for TM61 procedure.

Return Period Years	Rainfall Factor
T = 2	0.32
T = 5	0.45
T = 10	0.54
T = 25	0.65
T = 50	0.73
T = 100	0.81

iii) Shape factor S. From measurements using a polar planimeter the catchment area is 479.3ha therefore

$$A = 1.83$$

The direct length to the furthest point in the catchment is 3 km.

therefore

$$L = 1.86$$

thus $$K = \frac{1.83}{3.46} = 0.529$$

From fig. 30

$$S = 1.0$$

iv) Area A.

$$A = 1.83$$

v) Peak discharge Qp. Fig. 32 gives the peak discharge for various return periods.

C) Discussion of Results. The TM61 procedure gives figures for the peak flood-flows expected from rainfalls in the catchment. These figures require evaluation in

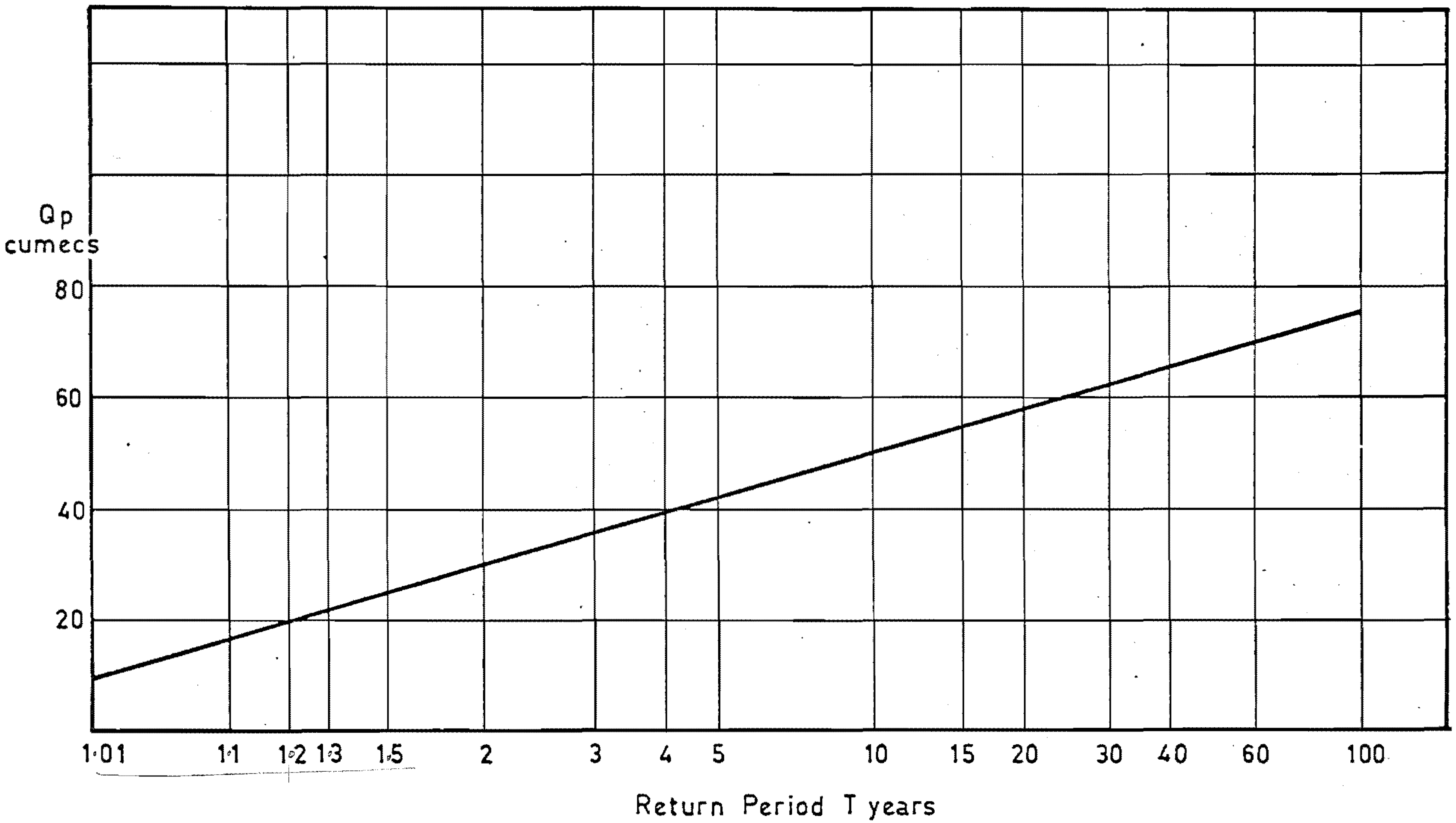


Fig.32 Discharge vs. return period for the Black Birch stream - Gumbel scale.

terms of the accuracy of the input data, and in terms of the emphasis given to each particular factor or coefficient in the formula.

For the slope characteristic (Ws), the accuracy of measurements of channel slope and length depend on the accuracy of the maps used and the easy identification of the main stream channel on that map. For the Black Birch catchment there is no more accurate map than the one used, but some problems were experienced in tracing accurately the main stream-channel especially in the higher reaches of the catchment. The channel chosen was one with its origin close to Mt. Annette since this was the most easily identified channel on the map and in the field. Of the two measurements the channel length is the more critical because of scale factors in fig. 28.

The infiltration and ground-cover characteristic (Wic) is the most qualitative term in the formula. While use of the hypsometric curve makes part of the choice quantitative, the major part of the choice must be based on qualitative observations and experience. Field observations suggest that the soils in the catchment are highly absorbent, but the impermeable glacial material and bedrock close to the surface may cause prompt sub-surface flow to be a major feature of the catchment. In un-vegetated areas the rock is in general intensely jointed and frequently covered by a layer of scree so that water movement could be restricted, and runoff is probably only slightly more rapid than in the vegetated areas. The infiltration and ground-cover characteristic was chosen with these characteristics in mind.

For the rainfall factor (R) data are derived from Robertson (1963). To test the accuracy of these date the method was extended to give depth values for a duration of 24 hours with various return periods. These values were compared with values obtained in earlier sections of this study using data from the N. Z. Meteorological Service and analysed using the Bumbel method. In statistical tests of the means of the two sets of values (using Student's "t" test) were found to be significantly the same at the 5% level of confidence. Therefore the rainfall depths calculated for the time of concentration are probably reliable. Maxwell (1962) noted large increases in rainfall depth with altitude but for short durations this variation is probably not significant. The time of concentration can be fairly arbitrary as long as it is less than two hours. The figures for rainfall intensity derived using the time of concentration are within the same order of magnitude as those commonly experienced in the area. The intensities for the particular return periods are shown in table 8.

Table 8 - Rainfall intensities.

Return Period	Rainfall intensity
T = 2	27 mm/hr.
T = 5	38 mm/hr.
T = 10	46 mm/hr.
T = 25	56 mm/hr.
T = 50	63 mm/hr.
T = 100	69 mm/hr.

The catchment shape factor (S), and the area factor (A), depend on the accuracy of the maps available and the accuracy of the measurements taken from them. Because of the prominent ridge lines the catchment boundaries are easily determined and direct measurements of area and length can be made accurately.

The values for the infiltration and ground cover characteristics (Wic) and the rainfall factor (R) are the most difficult to determine. Their importance in the formula is therefore greater than the importance of factors for shape (S) and area (A). Of the two, the rainfall factor is probably more important because it varies with the return period while the infiltration and ground-cover characteristic remain constant.

Empirical methods cannot be expected to give absolute values for flood peaks but they can give an indication of the order of magnitude and an indication of the relative size of flood peaks for various return periods. Even this information is useful for the calculation of risks. For example if fig. 32 is redrawn on normal graph paper it can be seen that the flood peaks increase rapidly up to the 20-30 year return period and then the curve flattens out (fig. 33). If the risk is assessed in mainly economic terms it may be found that a flood of this order of return period may be the maximum justifiable design-flood.

5.4.3 The Rational Method.

A well-known and relatively simple alternative to the TM61 procedure is the Rational method which has the formula:

$$Qp = CiA$$

where Qp = peak discharge.
C = a catchment runoff coefficient.
i = design rainfall intensity at the time of concentration in inches/hour (1in = 25.4 mm).
A = area of catchment in acres (1 acre = 0.4 ha).

The value for the runoff coefficient can be derived from a number of charts (see examples in Chow 1964 and University of Canterbury 1973), or the method can be made more quantitative if the term for the runoff coefficient is abandoned and the term for the design rainfall intensity is modified to give the "effective rainfall intensity". The effective rainfall intensity can be defined as the design rainfall less the rate of infiltration, that is the quantity of rainfall available to form

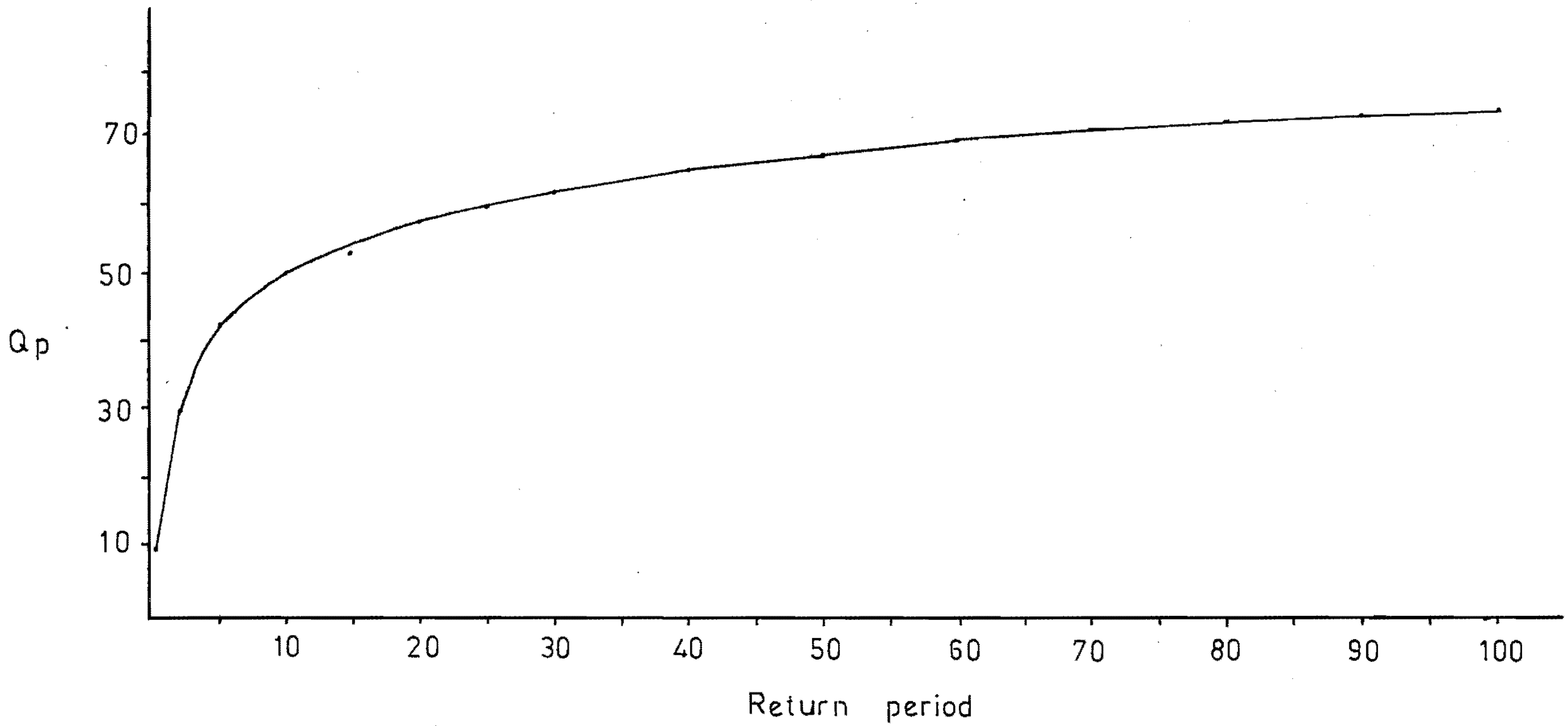


Fig.33 Discharge vs. return period for the Black Birch stream - arithmetic scale.

overland flow. An assumption is made that interception storage and evapotranspiration is insignificant.

Infiltration is a measure of the flow of water through the soil surface. Initially the rate of infiltration may be high, but usually reduces to a much lower constant rate controlled by the zone in the soil with the lowest rate of water transmission. The rate of infiltration can be no greater than the permeability of that layer. For a short duration rainfall the infiltration rate is nearly equivalent to the permeability of the surface layer. If, as is the case with the Black Birch catchment, a thin soil layer overlies an almost impermeable substrate, and both have steep surface slopes, then the infiltration rate is controlled by the rate of water movement downslope through the soil layer. If hydrostatic forces in the soil layer are ignored the maximum possible infiltration rate is equal to the permeability of the soil layer.

Permeability can be measured by a variety of laboratory and in situ tests, but in this study it was found necessary to construct a permeameter (details of the construction and calibration are outlined in appendix 3). Thirty soil samples were tested and there was about a 30% rejection rate due to piping failure or impermeable samples. The average value for the coefficient of permeability was 1.7×10^{-3}mm/sec. This gives a maximum possible infiltration rate of 6.1mm/hour over the areas in the catchment covered by glacial deposits and colluvium. No value for the infiltration rate could be determined for the areas of bare rock and scree, but as an approximation based on qualitative observations the same value is used. The design and effective rainfall intensities for various return periods are shown in table 9.

Table 9 Design and effective rainfall intensities.

Return period	Design mm/hr	Effective mm/hr
T = 2	27.0	20.9
T = 5	38.0	31.9
T = 10	46.0	39.9
T = 25	56.0	49.9
T = 50	63.0	56.9
T = 100	69.0	62.9

By using the Rational formula

$$Qp = CiA$$

and substituting values of effective rainfall for the terms C and i the peak flood-flows for various return periods are shown in table 10.

Table 10 Peak Flood Flows.

Return period	Qp cumecs	% difference
T = 2	27.2	8.0
T = 5	41.8	0.5
T = 10	52.1	4.2
T = 25	65.1	8.5
T = 50	74.3	9.3
T = 100	83.6	11.5

The percentage difference between the results obtained using the TM61 procedure and the Rational method can be seen. Limitations on the accuracy of the results from the Rational method are similar to the limitations inherent in the TM61 procedure.

5.4.4 Channel Capacity.

A) The Manning Formula. The derived peak flood-flows for a variety of return periods can now be compared with the capacity of the channel. The area of particular concern is in the lower channel reaches. One method of determining the channel capacity is to use the Manning formula:

$$Q = (1/n)AR^{2/3}S^{\frac{1}{2}}$$

where Q = discharge.

n = Manning's coefficient of bed roughness.

A = cross-sectional area.

R = hydraulic radius.

S = slope of the energy gradient.

Metric units are used throughout.

The Manning formula was originally intended for use with uniform or gradually varied flow conditions, and was developed from laboratory flume tests. Its major use is in the design of canals, sewer systems and other hydraulic works. It can be applied to catchment studies where its main value is in the calculation of flood flows when for some reason the flows could not be recorded during the flood event. In this application it is often referred to as the "slope-area method".

With the exception of the "n" value all the terms are quantitative. The value for the Manning coefficient (n) can be determined from a number of charts and photographic comparisons, and in this case Barnes (1967) and Chow (1959) were used. Various degrees of complexity can be included in the formula, especially in consideration of the value for S, but for this study a measured channel cross-section from below the Sebastopol bridge was taken to be uniform over a distance of 20m; the value for S was taken to be the slope of the water surface present when the cross-section was measured (summer thaw conditions with flows slightly above normal), and the value for n was considered constant over the whole cross-section. The typical cross-section is shown in fig. 34. Q is calculated for successive stages above the channel bottom and the results are shown in table 11. The water velocity can also be calculated using the formula:

$$V = (1/n)\, R^{2/3} S^{\frac{1}{2}}$$

and the results are also shown in table 11.

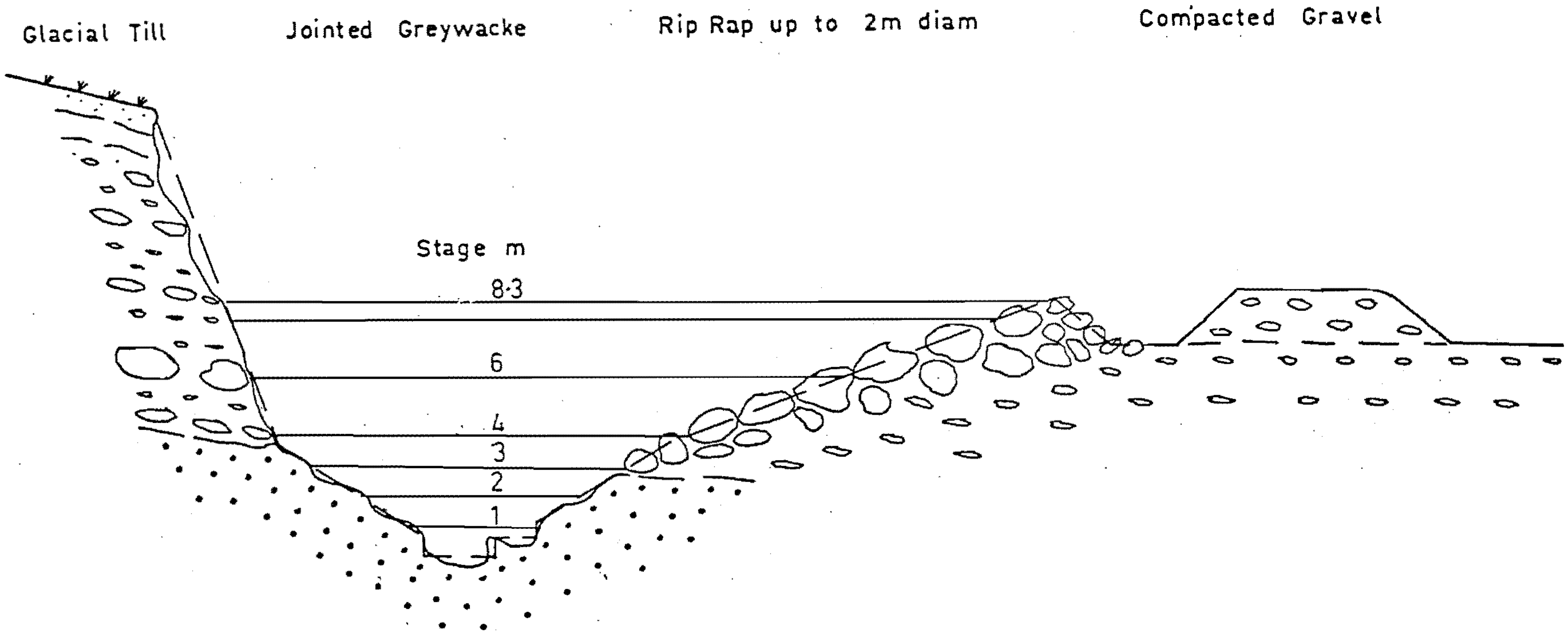


Fig.34 Typical cross-section of the lower reaches of Black Birch stream.

Table 11. Stage-discharge calculations.

Stage m	A m^2	Wetted Perimeter m	R m	S m/m	n	v m/s	Q cumecs
1.0	3.20	6.5	0.49	0.05	0.063	2.21	7.06
2.0	9.36	10.3	0.91	0.05	0.063	3.33	31.19
2.5	13.66	12.2	1.12	0.05	0.063	3.83	52.26
3.0	19.08	14.1	1.35	0.05	0.063	4.33	82.68
3.5	24.94	16.1	1.55	0.05	0.063	4.74	118.25
4.0	31.56	18.1	1.74	0.05	0.063	5.13	161.92
6.0	63.68	25.9	2.46	0.05	0.063	6.46	411.57
8.0	109.80	33.7	3.26	0.05	0.063	7.80	856.17
8.3	126.12	36.0	3.50	0.05	0.063	8.17	1030.90

B) Discussion. By comparing the values of Q derived using the Manning formula and the expected flood peaks derived from either the TM61 procedure or the Rational formula, it can be seen that floods with a return period up to T = 22 can be accommodated in the first 2m stage, and the floods with return periods up to T = 100 can be accommodated in the first 3m stage. But before the simple conclusion outlined above can be accepted a number of important features require discussion.

The methods of determining both the expected flood flows and the capacity of the channel are based on empirical formulae and a large number of assumptions have been made so that these simple formulae can be used. The assumptions made in calculating the expected flood peaks have already been discussed. The assumptions made in the Manning formula are that the cross-sectional area does not change during any one flow event, that the channel is of uniform shape, that the slope of the energy gradient is constant for all flow events, and that the value for n does not change during any one flow event. Alluvial stream-beds are characterised by continual change and the Black Birch stream is no exception. Considerable changes can often be seen following minor floods in the upper part of the stream channel, and since the section of the stream channel under discussion has recently been excavated and has probably not yet reached equilibrium, changes in the cross-sectional area could be expected. During floods large quantities of bedload material could be expected to move downstream thus effectively reducing the cross-sectional area.

The channel shape has an important influence on the slope of the energy gradient; rapid changes in the bed or sides of the channel cause rapid changes in the profile of the water surface and thus affect calculations of the slope of the energy gradient. Channel curvature complicates the situation because of variations in stream velocity, surface profile, and areas of sediment deposition and scour around the curve. The value for n normally decreases with increasing flow but this depends to a large degree on the shape of the channel cross-section.

5.4.5 Discussion.

There is probably very little chance of a flood with a return period of T = 100 overtopping the excavated channel; the flood, with T = 100 calculated using the TM61 procedure, would have to be 13 times larger than the channel capacity calculated using Mannings formula. Even allowing for assumptions and errors in both calculations, and the hydrology of the larger area, the margin between the two calculations is significant.

Because of the method of channel formation, scour could be the most critical factor in determining the effectiveness of the protection works along the channel. The design concepts that appear to have been used in constructing the channel are outlined in appendix 10 of Acheson (1968). In brief, the channel is rock-raked and the larger particles are used as rip-rap along the sides of the channel. The finer material is removed by subsequent floods, and the process is repeated until a presumably stable channel has been formed.

The method overlooks the fact that in an environment of active aggradation, such as on the fan, all the materials present must have been transported to, and deposited on, the fan by the stream (except for a small amount of material that may have been derived from rock-falls off the Sebastopol buttress). To be certain that this rip-rap material cannot be transported further by the stream implies that either the climate or the vegetation in the catchment has changed so that flood peaks are no longer as large as those which originally transported the material.

There is certainly evidence that vegetation has changed due to pre-European and European burnings, and a gradual increase in interception storage and evapotranspiration following the burning could decrease the size of the flood peaks. The increase would probably be insignificant after vegetation was re-established. Long-term climatic change has occurred since the last glacial advance and may have resulted in an increase in temperature and possibly in rainfall. Since the late 1800's the Tasman and Mueller glaciers have downwasted. This suggests a warming of the climate or possibly an increase in rainfall, yet from the records available no significant increase can be found (Kolb 1958). Evidence for significant climatic and vegetational changes is therefore slight and if they did occur the changes would probably be so small as to have no noticeable effect during the design-life of the structures on the fan.

Some of the boulders used in the rip-rap are larger than those found on the fan apex and may have been moved from further upstream or from the surface of the apex (possibly the cause of the inconsistent results in tractive-force and particle-size studies of the 730m traverse on the fan). Particles with an intermediate axis of up to 1m are common in the rip-rap, and assuming they would be moved along a channel with a slope of 0.05 m/m the dS product would be around 0.05.

The original tractive force formula was adapted to give the dS product which is the product of the length of the intermediate axis of a particle and the slope on which it was deposited. The length of the axis was taken as an approximation of the depth of flow. When considering the channel, however, the depth of flow can be approximated by the hydraulic radius; thus for floods of a return period of up to T = 100 the maximum dS product will be 0.064.

Since the dS product for particles in rip-rap is less than the dS product of the stream for a flood of T = 100 it is probable that these particles could be moved by a flood of this return period. Fig. 35 shows the relationship between discharge, stage, return, period, dS product, and length of the intermediate axis. The graph shows that particles with an intermediate axis of 1m can theoretically be moved by a flood with a return period in excess of T = 4 years.

Three qualifications must be noted. In the first place that the figures used in the graph are based mainly on empirical relations. The return-period-discharge relationship is based on the TM61 procedure, the stage-discharge relationship on the Manning formula, and the stage-dS product relationship is based on approximations of the tractive-force equation. The second qualification that should be considered is that a dynamic system is involved, and a small variation

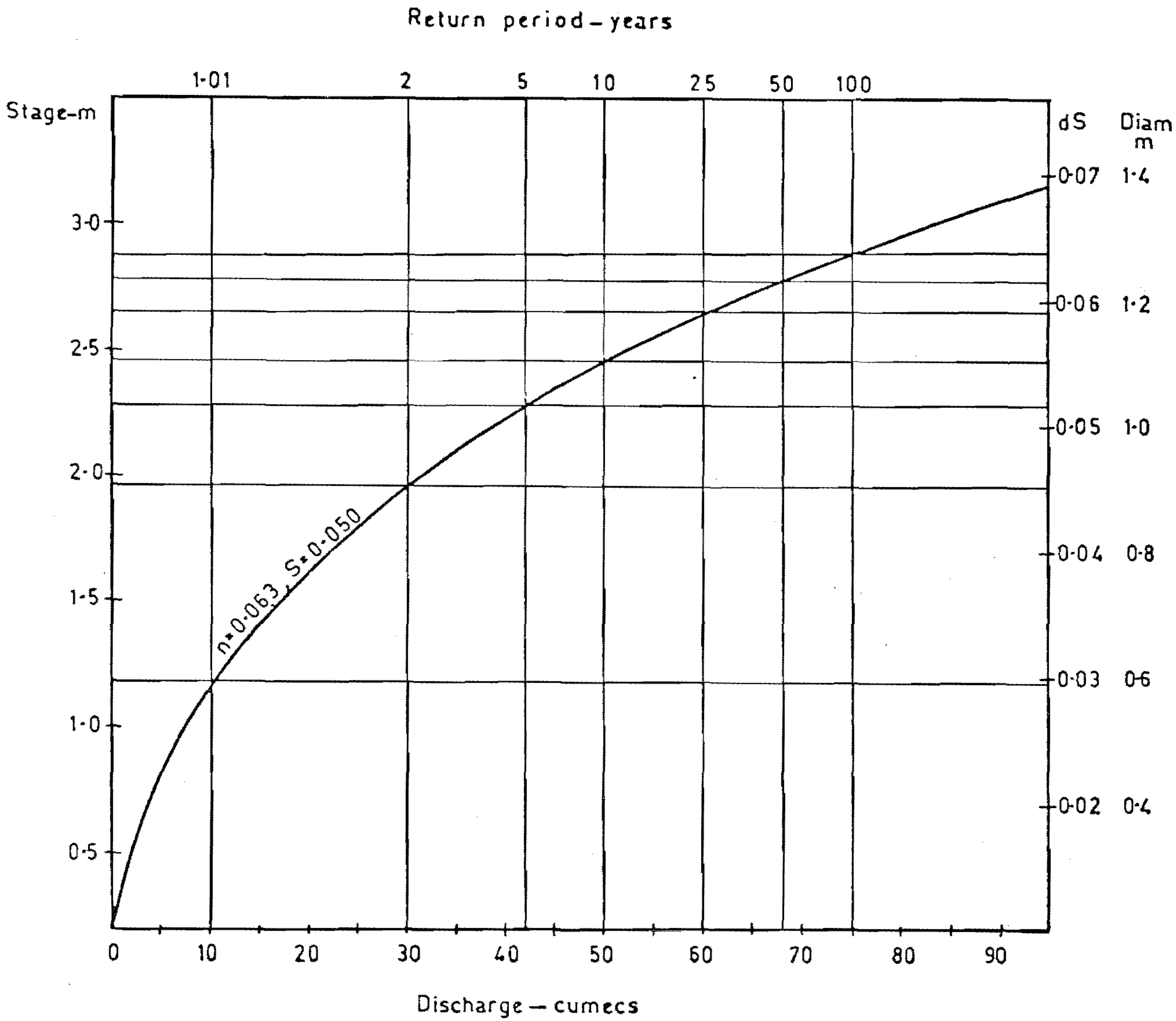


Fig.35 Stage-discharge-return period-dS product diagram for the typical cross-section of Black Birch stream.

in the value of n or S due to a change in the cross-sectional characteristics or profile of the stream during a flood event can alter the shape of the stage-discharge graph greatly, thus changing the return period-dS product relationship. The third qualification is that the graph only applies to the section of the channel that was considered as typical; for every other section of the channel it is possible that the relationships are not the same.

The calculations give an approximation of the size a flood would have to be before the protective works in the channel were damaged. This does not necessarily imply flooding on the fan surface. It should be noted that a flood with a return period of T = 4 contains 52% of the flow of a flood with a return period of T = 100. A flood capable of damaging the protective works and consequently causing the flooding of the fan-surface would probably have a return period of significantly greater than four years.

5.5 SITE SUITABILITY

It would appear that the decision to site buildings on the fan was considered in terms of aspect, climate, access, and a variety of social and economic features. From a geological point of view the site offers advantages of foundation conditions, slope, and drainage that are not very easy to find elsewhere within the Park boundaries. In what way?

It could be that in comparison with other sites the combined advantages of the Black Birch fan site outweighed the hazards inherent in the site, and the geological risk is therefore acceptable. The advantages of the site will continue to increase as development proceeds because of the social and financial disruption that would be caused by the use of an alternative site.

5.6 IMPACTS.

Any engineering work involves some impact of the environment. From observations and using Leopold (1971) as a basis the following actions will have a disturbing effect on the environment of the Black Birch fan:

i) River control, channel excavation, channel revetments, check dams.

ii) Alteration of ground cover, paving and sealing, landscaping, weed control.

iii) Addition of buildings, oxidation ponds, roads and trails, pipelines, transmission lines.

During the period of construction these impacts could be high, and visually at least, be out of keeping with the rest of the environment. The use of landscaping will probably lessen the impact.

In the long term little can be done to improve the appearance of the river control works, and indications are that continual maintenance of the channel will be required. This may involve the addition of rip-rap to the upper reaches, and removal of sediment from the lower reaches of the channel. To conform with National Park ideals rip-rap will have to be aquired and sediment disposed of outside the park boundaries; control may be required to minimise disturbance to the environment and to the park user's enjoyment of the area during this work.

6. SUMMARY.

The increasing pressure on tourist facilities at Mt. Cook has forced building onto a recently active fan surface at the outlet of a mountainous catchment. Climatic conditions are severe, and of major importance are high intensity rainfalls occurring mainly in the summer months. Vegetation in the catchment comprises a fairly typical alpine community with vertical zonation due partly to climate and partly to the nature of the soil substrate. Two possible episodes of burning can be identified.

The area is within the Torlesse Group of greywacke, argillite and low grade schist of Permian to Jurassic age uplifted most recently in the Kaikoura Orogeny. Two major faults trend north-south and between them schist crops out. A major anticline occurs along the southern boundary of the catchment, and possibly several smaller anticlines occur to the north of the Great Groove Fault. Pleistocene glaciations affected the area and retreated from it sometime between 5120 years B. P. and 530 years B. P. A deposit, probably of outwash material, is found in the catchment and has a vertical thickness of 150m. This material is best described by the obsolete term "boulder clay". Large areas of scree material are found above the outwash.

Tractive-force studies were carried out on the fan, and a decrease in tractive-force and maximum particle-size down fan could be identified in three

out of four traverses. A positive correlation between maximum particle-size and slope was observed. No significant areal variations in granule and sand size particles were found. Three factors leading to fan formation, flood flows, sediment supply, and water losses, are suggested and the mechanism outlined. Stream cross-sections and particle sizes were measured in the upper reaches of the stream. A longitudinal profile was derived and it was determined that sediment size increases downstream towards the gorge section at the apex of the fan. This is probably the result of an over supply of sediment in the upper reaches of the stream.

Area-altitude analysis was carried out on the catchment and about 50% of the area is below 40% of the total relief. An average valley wall profile was derived and the average slope of the catchment was found to be 37.8°. The surface area of the catchment was found to be 617ha compared with the map area of 479ha. Quantitative slope-analysis was performed using two methods to give the areal extent of various slopes. The average slope determined by this method was 37°. Slope stability was discussed and it was observed that landslides are not a common feature of the catchment. Avalanches descend part of the stream channel in late winter; their classification is suggested, their movement described, and their importance in depositing debris in the channel is noted.

The concept of geological risk is introduced. Possible geological risks caused by avalanches, fires, landslides, earthquakes, high intensity rainfalls and floods, and the possible interactions between them, are described. It is concluded that hazards from avalanches and landslides are not significant, that hazards from fires depend on human behavior and management policies, and that high-intensity rainfalls create hazards in the form of floods. Earthquakes and floods are thought to be significant risks.

Little contemporary evidence was found to support the idea that earthquakes would be a significant hazard although this contradicts historical evidence. It was thought best to use a method widely used throughout New Zealand to asses earthquake risk and the need for further study was stressed.

To assess the hazard from floods, an approximation of the size of flood had to be made. Two methods are used; the first is the empirical TM61 Procedure and the second the Rational method. For the latter an approximation of infiltration was required which entailed the design and construction of a constant-head permeameter. Both methods gave similar results for floods of equivalent return period. The capacity of the channel to handle these floods was calculated using the Manning formula. The stability of the material in the channel to the flow conditions was calculated using the tractive force equation.

It is determined that the channel has a capacity 13 times greater than the maximum calculated flood, but that the channel material will be unstable in flows with a return period of four years. Because of the number of assumptions in the calculations it is concluded that a flood will have to have a return period significantly greater than four years before flooding will occur on the fan.

The advantages of the site are discussed and it is determined that probably the social and economic factors outweigh the threat from geological hazards, and that in terms of the total development the geological risk is probably acceptable. The most serious impact on the environment that the development will have, will be the continual maintenance of the channel.

Three appendices are attached. The first is an outline of the statistics of extremes used in analysing meteorological and hydrological data. The second is a bibliography of geology and glaciology of the Mt. Cook National Park. The third is an outline of the design and construction of a constant head permeameter.

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APPENDICES.

LIST OF APPENDICES.

APPENDIX 1 - THE STATISTICS OF EXTREMES.

1. Introduction.

If an infinite number of rainfall of streamflow readings are recorded there will be high and low values, but the majority of the readings will tend to be somewhere near the central value. If the frequency of occurrence is graphed against the quantity of rainfall or streamflow a curve approaching the normal distribution should result. If a sample is taken from the infinite population and graphed in the same way it should approximate the shape of the infinite population, if it is a representative sample. Should a sample from the infinite population be intentionally biased to the high or low values a skewed distribution results.

With maximum 24 hour rainfalls the sample from the total number of rainfalls is biased in favour of heavy rainfalls with a low frequency of occurrence. The graph of frequency of occurrency against quantity of rainfall can be seen in fig. 36. The curve is left-skewed, thus the sample can be considered to be a sample of extreme values. Extreme values can be analysed by a number of methods, but the most common method for meteorological or hydrological data is the Gumbel method.

For the purposes of this study a worked example of the Gumbel method is shown using data of the maximum

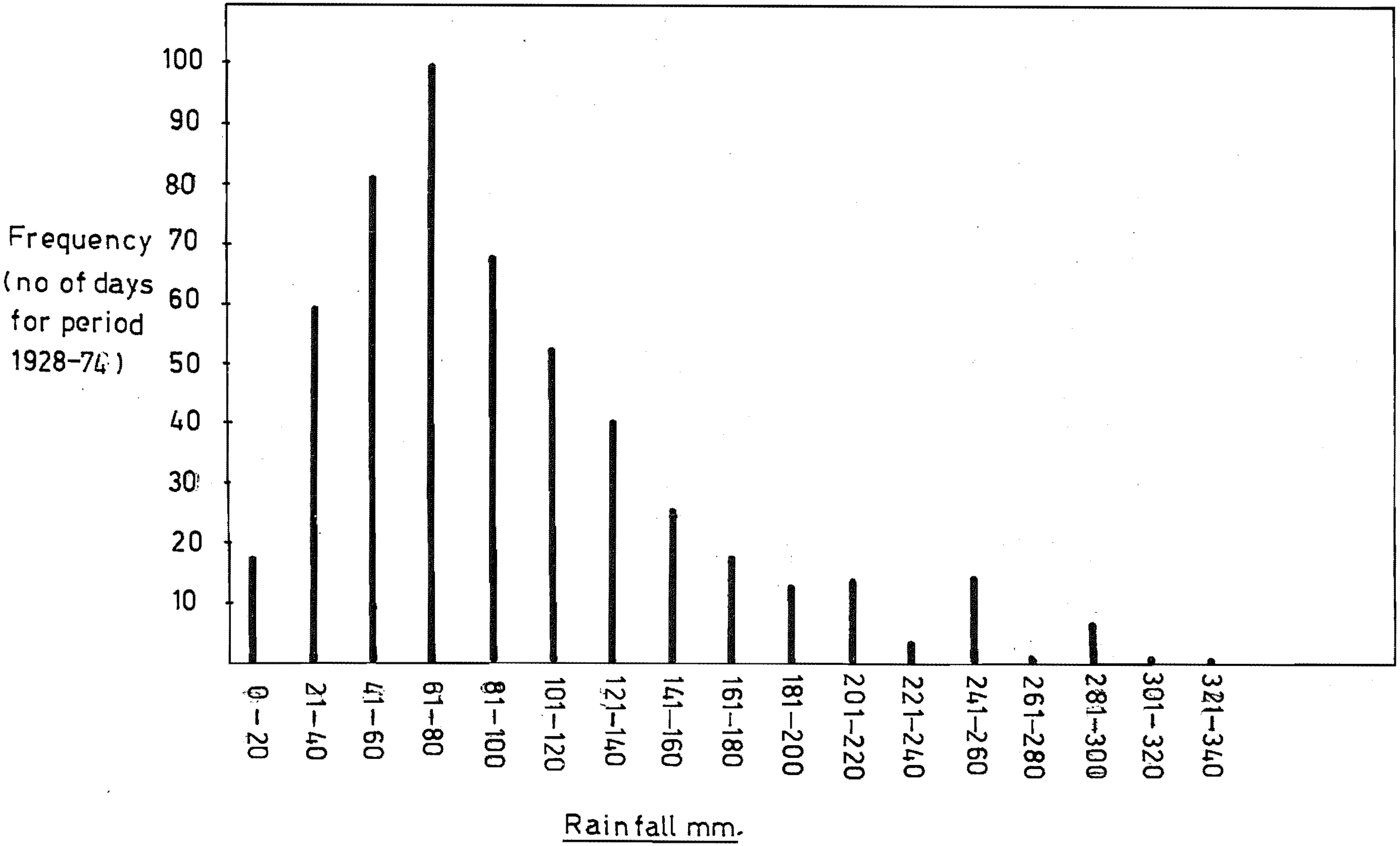

Fig. 36 24-hour rainfall depth frequency histogram.

24-hour rainfall for each year on record for the period 1928-1974. References by Robertson(1963) and the World Meteorological Organization(1967) give a more comprehensive summary of the theory behind the method.

2. Worked Example.

Step 1. Records of yearly maximum 24-hour rainfall for the period 1928-1974 cover 35 years. The number (n) of discrete values in the sample therefore is 35. Each discrete value is a record of rainfall in mm and is designated X. The observed rainfalls are listed in ascending order and ranked. The rank is designated m and is in fact the cumulative relative frequency of each observation.

Year	X(mm)	M	Φ	T
1930	89.9	1	.027	1.03
1971	124.8	2	.056	1.06
1963	153.7	3	.083	1.09
1951	157.5	4	.111	1.12
1953	160.5	5	.139	1.16
1939	162.6	6	.167	1.20
1966	171.5	7	.194	1.24
1974	174.5	8	.222	1.29
1972	176.1	9	.250	1.33
1947	177.8	10	.278	1.37
1968	182.4	11	.306	1.44
1932	189.2	12	.333	1.50
1960	199.4	13	.361	1.56
1965	199.4	13	.361	1.56
1959	204.5	15	.417	1.72
1954	208.3	16	.444	1.80
1961	209.0	17	.472	1.90
1964	221.2	18	.514	2.06
1958	235.0	19	.528	2.12
1933	243.6	20	.556	2.25
1949	248.9	21	.583	2.40
1948	254.0	22	.611	2.57
1973	259.0	23	.639	2.77
1962	262.1	24	.667	3.00
1969	264.2	25	.694	3.27
1967	287.0	26	.722	3.60
1934	288.8	27	.750	4.00

Table 12. Calculation of T.

Table 12 cont.

Year	X(mm)	M	O	T
1950	292.1	28	.778	4.50
1952	292.1	28	.778	4.50
1940	295.9	30	.833	6.00
1936	299.7	31	.861	7.19
1931	305.3	32	.889	9.01
1955	317.5	33	.917	12.1
1935	335.3	34	.944	17.9
1942	558.8	35	.972	35.7

Step 2. The "plotting position", that is the probability of non-exceedence of the rainfall of the m^{th} rank is calculated using the formula:

$$\Phi = \frac{m}{n + 1}$$

However statistics of rainfall are most meaningful when expressed in terms of "recurrence interval" or "return period". The return period is the mean number of years within which a particular rainfall will be equalled or exceeded.

The plotting position can be expressed in terms of return period T using the equation:

$$T = \frac{1}{1-\Phi}.$$

This means that the highest observed value ($m = n$) is assigned a return period of ($n + 1$) years. If the highest observed value was assigned a return period of n years then the following situation would result: with the series of 35 rainfalls ranked 1 to 35 in increasing order of magnitude, the largest rainfall has a probability of 35/35. If the series was arranged in decreasing of magnitude the largest rainfall would have a probability of 1/35 so that the sum of the two probabilities, which in theory should always be 1, is 36/35.

Step 3. T or Φ is plotted against X on Gumbel probability paper. Gumbel probability paper has an arithmetic X axis and the Y axis is graduated with three related scales:

i) A linear Y scale.

ii) A probability scale on which the graduations are related to the Y scale by the equation

$$\Phi = \exp\,(-e^{-y})$$

which simplifies to

$$y = -\log\,(-\log\,\Phi).$$

iii) A return period scale which is related to the probability scale by the equation

$$T = \frac{1}{1-\Phi}$$

Commercially-printed Gumbel graph paper is available marked in terms of the return period. T and X are plotted on Gumbel probability paper in fig. 7.

Step 4. With reference to fig. 7 the plotted points fall approximately around a straight line. A line drawn by eye can be fitted or a line canbe fitted using the equations

$$x = y/\alpha + u \quad \text{or} \quad y = \alpha(x-u)$$

where $1/\alpha$ = parameter of dispersion = 0.785.

and u = parameter of central value = $\bar{x} - \underline{0.577}$.

s = standard deviation.

$\bar{x}$ = mean.

In this case.

$$\bar{x} = \frac{\Sigma X}{n} = 234.3 \text{ mm}$$

$$s = \sqrt{\frac{\Sigma X^2 - n(\bar{X}^2)}{n}} = 81.1 \text{ mm.}$$

thus $1/\alpha = 63.3$ mm

$$u = 197.8 \text{ mm.}$$

By using these values in

$$y = \alpha(x-u)$$

$$\hat{x} = 197.8 + 63.3y$$

Where $\hat{x}$ is a particular value on the X scale.

This is a straight line adjusted to observations on the probability paper.

Step 5. The equation

$$\hat{x} = 197.8 + 63.3y$$

is solved by giving arbitrary values to y. Since y is related to T, rainfalls for specified return periods can be found. Values for y can be found by using the formula

$$y = -\log(-\log \Phi)$$

for the range of values in the sample, or it can be read directly from standard statistical tables.

Return Period T	2	5	10	25	50	100	years.
Value of Y	.37	1.5	2.25	3.2	3.9	4.6	
Value of 63.3y	23.4	95.1	143	203	247	292	
Value of u	197.8mm						
Estimate of $\hat{X}$ corresponding to T	221	293	340	400	445	489mm.	

$\hat{x} = 197.8 + 63.3y.$

Step 6. Confidence intervals for the rainfall estimates derived in step 5 can be calculated using Bernier and Veron's method where

$$\hat{x}_{\Phi} - T_2 S \leq \hat{x}_{\Phi} \leq \hat{x}_{\Phi} + T_1 S.$$

T_1 and T_2 are parameters, the function of n and of Φ. These values are read off a nomogram prepared by Bernier and Veron for confidence intervals of 70% and 95%.

Return Period	T	2	10	100 years.
Estimate of	$\hat{x}$	221	340	489 mm.
<u>Confidence interval of 95%</u>				
Values of parameters for				
n = 35	T_1	0.4	1.1	1.7
	T_2	0.21	0.6	1.12
Values of terms				
s = 81.1	$T_1 S$	32.4	89.2	137.9
	$T_2 S$	17.0	48.7	90.8
Upper limit of confidence	$\hat{x} + T_1 S$	253.4	429.2	626.9 mm.
Lower limit of confidence	$\hat{x} - T_2 S$	204.0	291.3	398.2 mm.
<u>Confidence interval of 70%</u>				
Values of parameters for				
n = 35	T_1	0.17	0.38	0.72
	T_2	0.14	0.32	0.59
Values of terms				
S = 81.1	$T_1 S$	13.8	30.8	58.4
	$T_2 S$	11.4	26.0	47.8

Upper limit of			
confidence $\hat{x} + T_1S$	234.8	370.8	547.4 mm.
Lower limit of			
confidence $\hat{x} - T_2S$	209.6	314.0	441.2 mm.

These values can be plotted on the graph and lines drawn between them to display graphically the confidence intervals (fig. 7).

3. Extrapolation.

Essentially the statistical procedures carried out consist of fitting data to a straight line and making the assumption that the straight line continues past the highest value plotted. The problem of how far the line should be continued is usually solved by using rule of thumb methods. Hydrologists using the Gumbel method to predict flood flows often do not extend the line beyond a value of the return period equal to twice the duration of the observations. However, if justified in terms of economics, the line is often extended to the predicted life of a structure that may be affected by floods and may thus exceed the above figure.

In this study since both the predicted life of the structures that may be affected indirectly by the rainfall, and the rule of thumb method outlined above, tend to give the same return period, an arbitrary figure of 100 years is the maximum predicted.

4. Conclusion.

On fig. 7 departures from the fitted line can be seen especially for the higher return periods. These departures may indicate that the length of record is insufficient for accurate statistical analysis, or that there is an incorrect assumption in the statistical procedure. The basic assumption in the procedure is that rainfalls vary in depth in a systematic way irrespective of origin, and that local climatic conditions do not alter the frequency distribution of the rainfalls. It can be seen that the value for T = 35.7 (558mm) has a large departure from the fitted line and that if this value was ignored a fitted line could be drawn that would be more representative of the other plotted values. But rainfalls of the same order of magnitude as T = 35.7 have also been recorded in 1914 (approximately 609mm by Du Faur 1915), and 1957 (491.2mm. by N. Z. Meteorological Service), but cannot be recorded on the graph because of incomplete yearly records. Two separate mechanisms of rainfall formation could possibly be hypothesised to account for the two markedly different groups of rainfall depths recorded. The fitted line is a compromise between the two groups, and for values of T = 1 to T = 4.5 it is a good representation of the data, for values of T = 4.5 to T =20 the line gives values that are too high, and for T = 20 to T = 100 values that are too low.

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APPENDIX 3 - DESIGN AND CONSTRUCTION OF CONSTANT - HEAD PERMEAMETER.

1. Design.

During the course of field study, measurements of permeability of the soil layers were required. It was found during preliminary experimentation that constant-head and falling-head permeameters used in the School of Engineering were unsatisfactory both in operation and for field use.

Requirements of performance and operation are listed. These are:

i) The permeameter should be able to handle undisturbed samples.

ii) The permeameter's performance should not be influenced by silt and clay-sized particles.

iii) The permeameter should be able to be transported and used in other than laboratory conditions.

iv) Costs and complexity should be kept to a minimum.

The permeameter was constructed to these specifications, with the following features:

i) Soil samples can be collected in the field in a relatively undisturbed state by forcing the sample tube into the ground. It was found that the samples could be preserved by wrapping plastic round them and sealing them tightly with tape. Up to 10 samples could be collected at one time and were light enough to be carried.

ii) Because the flow direction through the sample is against gravity, clay and silt-sized particles tend to remain in suspension; in all but very permeable samples the water collected after permeation through the samples was clear. The water pressure was found to be sufficient to cause flow, but not enough to cause frequent piping failure of the samples.

iii) The permeameter was light enough to be carried in one hand, and the only requirement for use was a standard 12mm garden-hose and water supply.

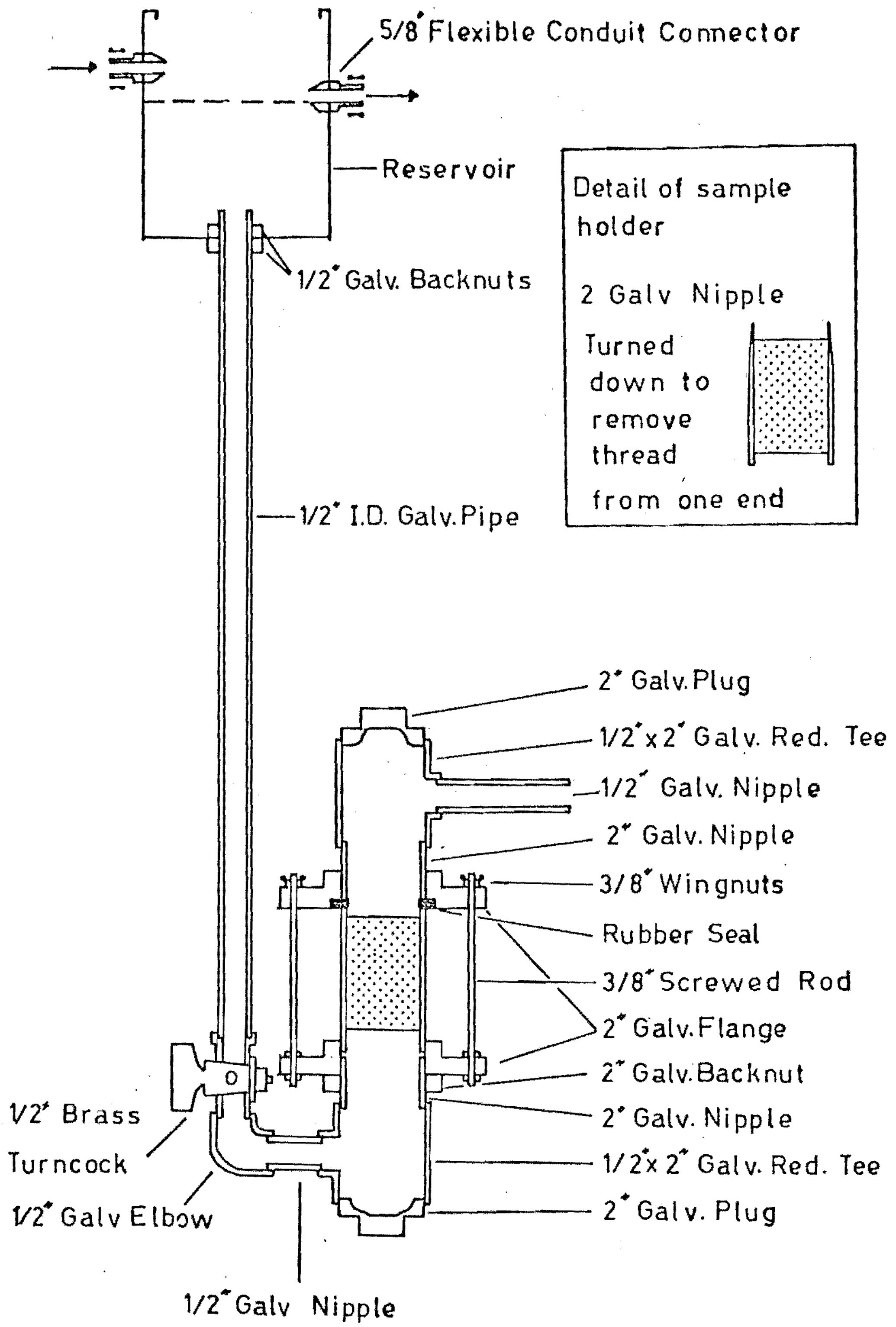
iv) Use of standard pipe fittings required a minimum of engineering; the only work that required special tools was turning down the sample holders, and turning out a cavity for the rubber seal. Parts cost about $25-00.

2. Construction.

Fig. 37 shows the construction of the permeameter.

3. Calibration.

Fig.37 Construction of a constant-head permeameter.



To test the operation of the permeameter ten ~~damples~~ samples taken in close proximity to one another were tested. The following results were obtained.

Q ml	L mm	h mm	A mm^2	t sec.	K mm/sec.
568	86	520	163.28	204.4	2.82×10^{-3}
568	76	520	163.28	86.9	5.85×10^{-3}
568	81	520	163.28	75.4	7.19×10^{-3}
568	86	520	163.28	62.1	9.26×10^{-3}
568	86	520	163.28	197.2	2.92×10^{-3}
568	84	520	163.28	44.8	1.26×10^{-3}
568	81	520	163.28	184.4	2.94×10^{-3}
568	100	520	163.28	74.8	8.94×10^{-3}
568	86	520	163.28	64.5	8.92×10^{-3}
568	90	520	163.28	74.6	8.07×10^{-3}

Using the formula:

$$K = \frac{QL}{hAt}$$

where

Q = quantity of water flowing through soil in time t.

L = length of soil sample.

h = constant-head difference.

A = cross-sectional area of soil sample.

K = permeability coefficient, in mm/sec.

Although there is some variation in the value of K, the order of magnitude is similar in each test, and for the purposes of this study, would appear to sufficiently accurate.